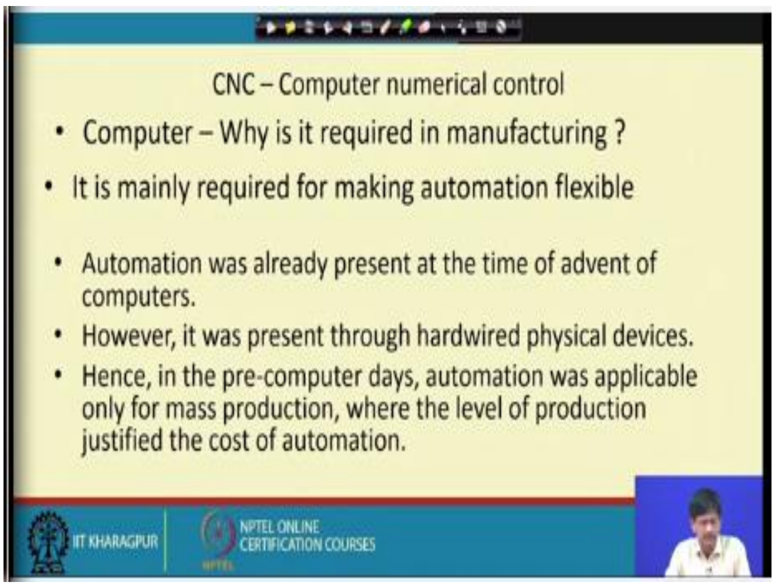
Metal Cutting and Machine Tools
Prof. Asimava Roy Choudhury
Department of Mechanical Engineering
Indian Institute of Technology-Kharagpur

Lecture-19
CNC and Non-traditional Machining Methods

Welcome viewers to the 19th lecture of the course metal cutting and machine tools. So, let us move right away into the subject. Today we will be having coverage of CNC that means computer numerical control and non-traditional manufacturing processes.

(Refer Slide Time: 00:41)



So, to start with computer numerical control, why is it required in manufacturing to incorporate a computer? This is mainly for making automation flexible, now what does this mean? What is automation? Automation is the running of a machine in automatic mode. So, that in case of a machine tool loading of the job or blank or bar is automatic, unloading is automatic, unloading of the finished part is automatic and all the machine operations which are in between like cutting, idle movement etcetera, all these movements are also automated.

There is no human intervention, so loading, unloading and all intervening operations they are automated. In case of automation we find that even before the advent of computers we had automation, how was it implemented? It was generally implemented in the form of hardwired physical devices, electronic circuits, mechanical devices mainly or electrical control circuits etcetera. So, it was hard wired devices are hard to change, hardware is hard to change and software is easy to change.

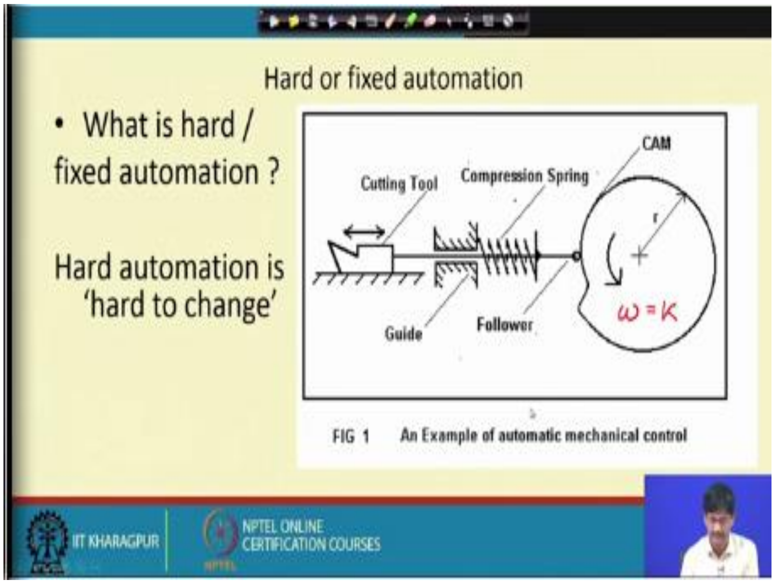
So, whenever there was the requirement of changes it was difficult to change this physical fixed hard automation. So, naturally when computers came into being there main strength was that computer's programming could be changed without much effort, without much cost and without much time. So, whenever changes were required in automation computers fitted the bill very suitably.

But why would we require changes in automation? Wherever the part design has frequent changes, that means in small lot and batch production, in that case hard automation is difficult. Because once we have made some hard automation device, it will be costly to change it, can we change say a machine part? It will be expensive. So, for mass production it was alright, we used to make special purpose machines with hard automation.

And maybe we are making millions of such similar parts without any change required in the hardware. So, hard automation or fixed automation that was very easily implemented in case of mass production. But when metal cutting scientist tried to implement the economies of hard automation in case of small lot and batch production, they found that very frequently physical devices which were required in hard automation whenever they needed to be changed there was heavy expenses incurred.

So, that way hard automation was not totally applicable in case of small lot and batch production, it was restricted to mass production. But computers made it possible to implement such automation in case of smaller levels or lower levels of production. Lower levels of production mean that a number of goods produced of similar components is not very high. So, in the pre computer day's automation was applicable only for mass production where the level of production justified the cost of automation. So, let us move on to the next slide.

(Refer Slide Time: 04:52)

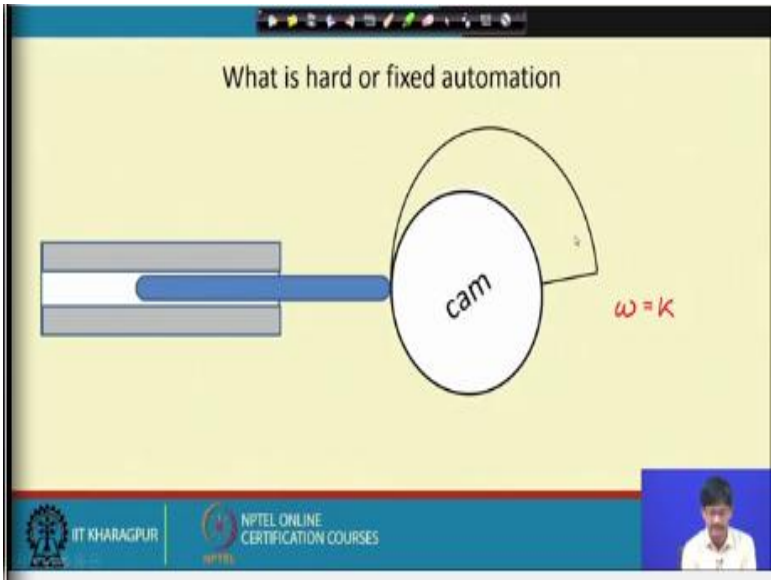


This is an example of hard automation, this is a physical device, what is it called? It is called a CAM, CAM is rotating it has a non circular profile, so that this change in radius all around will be applying ultimately a push on this follower and this follower is going to push this cutting tool. Cutting tool is going to have a straight line, linear motion which is going to be dependent upon the rate of change of radius with angle.

If this is proportional if this is an Archimedean spiral the cutting tool is going to have constant velocity forward motion if this is given uniform circular motion. Uniform circular motion basically means here omega is constant. So, if we put omega is constant, we will get velocity will be constant for the cutting tool, that means the feed forward motion will be at a constant rate.

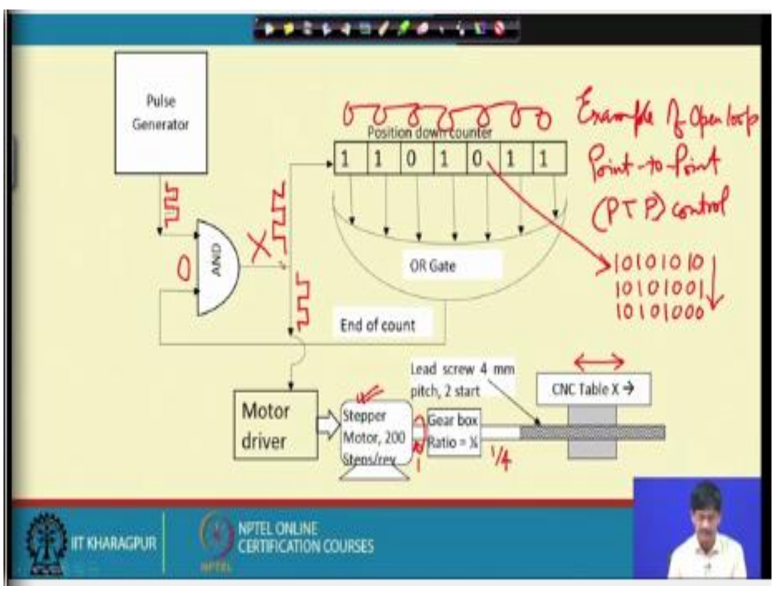
The moment this point comes after rotation, this will be rotating and this one comes this will be rapidly retracted under the effect of this compression spring. So, this is called the guide, this is the follower and this is the pushrod passing through, this is the cutting tool and this is a CAM and this is an example of mechanical controls for fixed automation and this main device is the CAM.

(Refer Slide Time: 06:38)



So, I have tried to just show in movement wise how this will look? Let us have a look, not very accurately shown but still something like this. This non equal radius pushes it out and suddenly it retracts back very fast when this point comes.

(Refer Slide Time: 07:11)



So, to proceed this is an example of what goes inside the CNC machine and this is an example of point-to-point control. So, I will just write it down here for your reference example of point-to-point it is called PTP, point-to-point control and this also in open loop mode. So, open loop I will write here, open loop. Example of open loop point-to-point control in case of computer numerical control device.

So, in these cases whenever we come across such examples it is best to identify the prime mover. The prime mover is called something called a stepper motor, what is the property of the stepper motor the stepper motor? The stepper motors are able to move by angular steps. Corresponding to pulses it receives from the pulse generator; see here pulses are coming out let me accentuate these pulses.

So, voltage pulses are being developed by the pulse generator and it is led through an AND gate and ultimately it reaches the motor driver. So, per pulse the motor will be rotating by one step and it crosses I mean it covers one full revolution, that means this shaft goes round once, this is the output shaft of motor this goes round once for 200 such steps. So, this goes round and this enters a gearbox with a ratio one fourth which means that if this rotates once this will rotate one fourth.

And this lead screw is having some pitch, so that this CNC table will be moved forward or backwards depending upon the direction of rotation of the lead screw. So, this will be moving corresponding to these pulses, so this is the basic control achieved here. So, if I change the frequency of the pulses, the speed of the CNC table will change, if I change the number of pulses going through and ultimately reaching the motor, the extent of motion will be controlled.

If I control the sequence, the pattern of pulses coming out from the pulse generator, then this will be either moving this way or that way. So, so many possibilities of control are there. Last of all if I put a number here, this is called a position down counter, it is a digital device. If I put a number inside these slots, in that case and if I take out their extensions and put it through an OR gate and unless and until all of them become zeros the output of the OR gate will never become a 0.

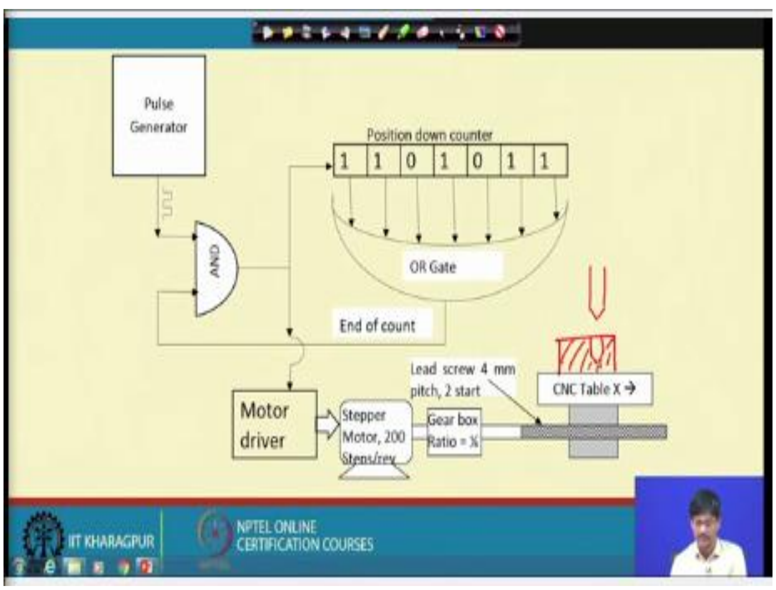
So, say all of them are zeros at a point in time. So, this output will be 0 and it will stop further pulses from coming to the motor, this is the way to stop motion. I can initiate the motion the pulse generator is always on, I can initiate the motion by putting some number here as long as it is not 1 and not 0, all of them. These pulses will go on and feed the motor and motor will be moving the CNC table.

But who is changing these numbers, these bits? This itself is changing, so these pulses which are coming this way and these pulses which are going that way, these pulses go and they are supposed to down count this counter. The number inside gets decremented by 1 for every pulse which comes here. So, every pulse which comes here decrements this content by 1, so say at a particular point in time it is 1010101 1, 2, 3, 4, 5, 6, 7, 8.

After that this will become 10101001 then 10101000, so this way it goes on changing with each pulse which is coming in and decrementing it, reducing its value by 1 each time, that is why it is called down counter. So, once it becomes 0 this way, this one stops further pulses from going through. So, this way control is achieved, we will definitely solve a numerical problem on this, so let us try the next time.

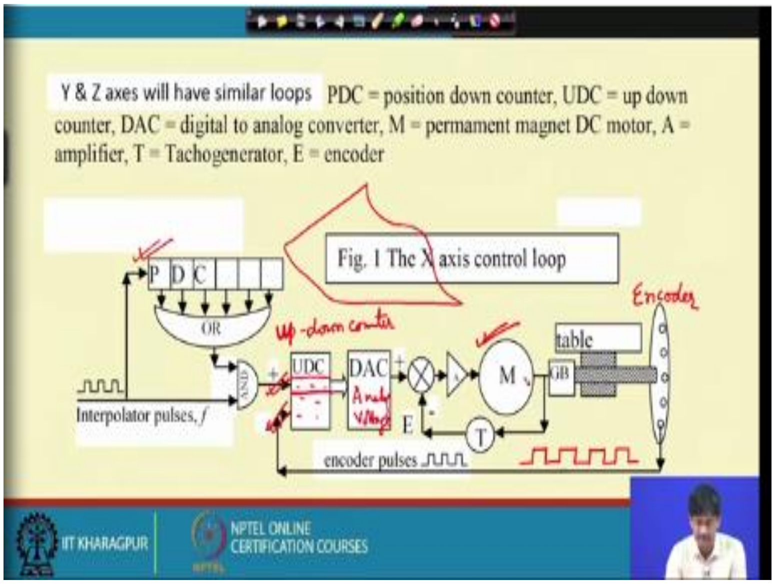
So, this is called point-to-point, there is no velocity control as such, whatever is the pulse generator output frequency CNC table accordingly moves with a constant frequency, a constant speed. But why would we want a constant speed? Say you are drilling**.**

(Refer Slide Time: 12:44)



If you are drilling, you are putting basically a job on top of this and this moves to a particular point and the drill comes here and it makes a hole here like that. So, when you are drilling you are really not interested in controlling the speed, you should move at a reasonably high speed and achieve the reaching attainment of a particular location where drilling is to take place. So, this point-to-point control is very suitable for drilling, for spot welding, for jig boring like that.

(Refer Slide Time: 13:22)



Next, this one control is used for a little more sophisticated type of machining operation that is a milling, lathe like that. So, what is this? Let us identify once again the prime mover, where is the prime mover? Yeah, here it is, this is the prime mover, the motor; here maybe it is a permanent magnet DC motor etcetera. Let us not be bothered about the nature of the prime mover, this is the prime mover.

And where are the pulses which were previously there? The pulses are still there they are coming from a device called interpolator? Interpolator basically controls the velocity and the ratio of the velocities along the different axis for a table, CNC table, a milling machine table. That position down counter is still there, position down counters basically control the extent of motion, this will be controlling the extent of motion.

Who controls the speed of the table? The pulse frequency will be controlling the speed of the table. So, pulses come here, position to the down counter again controls through that OR gate collectively taking all these values out and when they are compared and when they are ANDed with the interpolator pulses if this is 0 interpolator pulses are stopped.

But suppose they are let through then through this up-down counter, this is called up-down counter, it can count up as well as down, this can only count down. So, through the up-down counter to a digital to analog converter and then an analog comparator, we will go through all these when we solve the numerical problem. And then through the amplifier it reaches the motor, so motor is not getting pulses now but it is getting an analog voltage now, why?

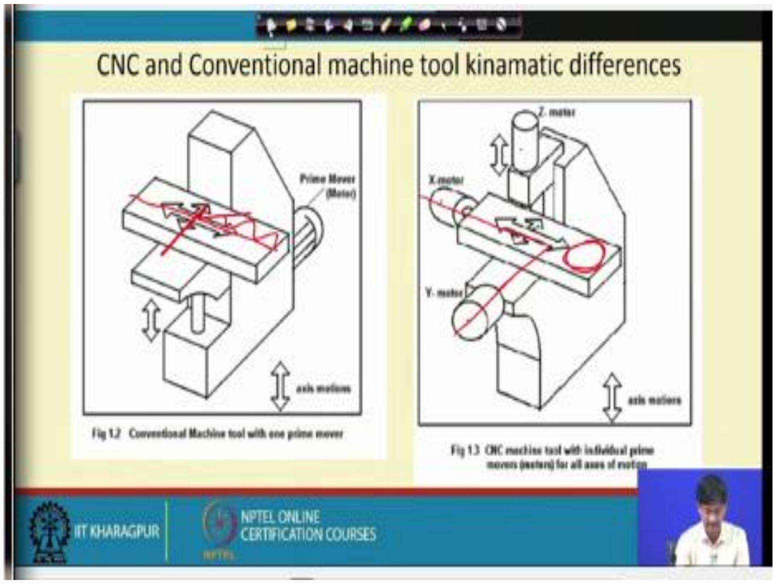
This is digital to analog converter, whatever number is getting accumulated here it is converted to an analog voltage and that is ultimately sent to the motor. So, motor gets the voltage and accordingly it develops the speed and it moves the table. Now here there is one feedback device called encoder, this is called the encoder. The encoder sends back pulses telling the machine where the table is.

So, these pulses go back and they are compared with the pulses which are coming in from the interpolator. So, it is just like a tank being filled up by a tap incoming pipe and an outgoing pipe. So, this one tells the motor yes, this particular level of water is getting filled up it is becoming higher and higher. So, the digital count is rising, the water level is rising, this one is telling us how much movement is already being carried out, so this is sort of outlet pipe, saying that ok, part of the job is already done.

So, some amount of water has gone down, so this one gets the water level down. So, basically when these two pulse rates balance like when these two water rates of coming in and going out when they balance the level balances. The value of the digital number here inside becomes constant and that is converted to a constant analog voltage. And accordingly the motor moves at a constant velocity getting us a constant speed.

This is the working of continuous control, by the help of this we can move along straight lines, we can move along circles, we can move along different types of free forms curves etcetera, to cut whatever surface that we want by computer control. So, interpolator pulses will be having the pattern corresponding to which the motor will be moving. Just now what we discussed about constant rates coming in and going out was for cutting of straight line cuts. At that time the motor is supposed to move at a constant speed. So, let us move on to the next concept.

(Refer Slide Time: 18:15)



So, in this way what we find is? The CNC, the conventional machine looks like this, remember one single motor in the milling machine supplies us this longitude motion, transverse motion and the vertical up-down motion and also the cutter rotation. Cutter has not been shown however in case of CNC what happens is each of the axis they are controlled separately to achieve absolute control over each and every axis.

Now what is the advantage here? The advantage is this that on the conventional milling machine we are cutting different profiles by combining the motions of these different axis. And immediately we have a disadvantage that whatever options are given by the gearboxes only those options we can have, may be the cross feed and the longitudinal feed if we want definite ratios to be existing, we can only look up the gearboxes and find out what are the different options different combinations which are possible.

But suppose I want a different option, suppose I want instead of moving the cutter in this direction I want to move the cutter in this direction, how do I do that? So, in that case I can have individual motors for each and every axis and control them from the computer directly. So, that if I want a circle to be cut I can give a voltage to the motor as V sin θ, V sin ωt and a voltage to the Y motor as V cos ωt and their combination will give me a circle.

If the speed correspond in a similar fashion to the respective voltage is applied to the motor. So, by this method I can cut practically any type of profile that I want without the help of physical devices by directly controlling their input voltage from the computer.

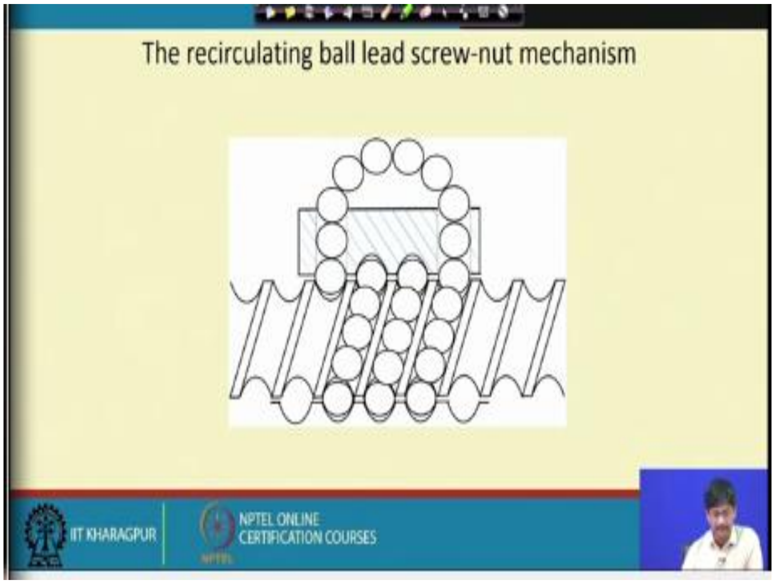
(Refer Slide Time: 20:40)

So, these are some of the parts that we have cut by computer control. See these profiles if you give this to an operator of a manually operated machine what he will say? He will say this is very difficult, I am going to charge you 5000 rupees in order to cut this because I have to draw this profile very accurately on the plastic part and then cut with great care and you have to pay me 5000 rupees with an advance of 500 rupees now itself, similar thing.

But what we did was? We simply made a program for the cutting of this one and the tool was automatically guided all through by the program, how was this done? Corresponding to each and every movement the interpolator sent a different pattern of pulses to the circuit which was controlling the movement of the table and accordingly it was done, everything was done automatically. What is this one?

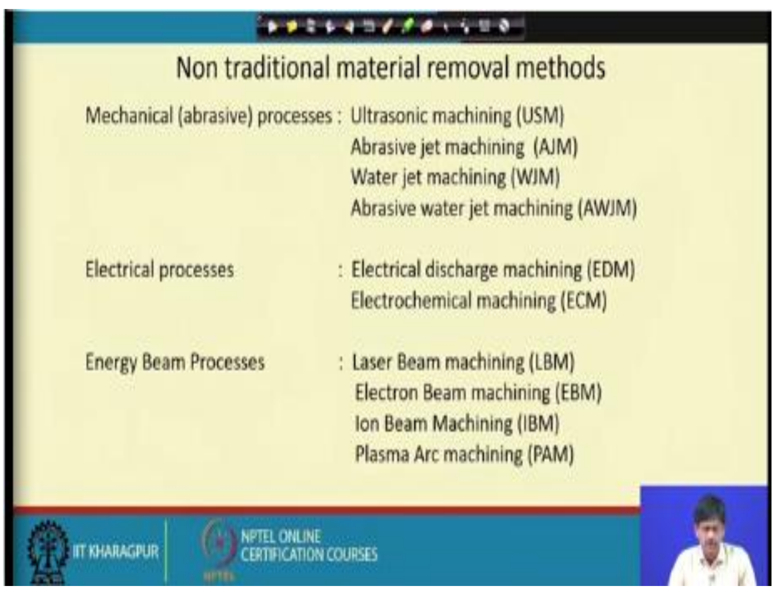
While these are two dimensional jobs, this is the three dimensional job showing a definite ups and downs and smooth surface on it on the top of a surface. So, we can cut 3D surfaces as well by computer numerical control without the help of any fixed hardware circuits or physical devices.

(Refer Slide Time: 22:13)



This is a device which we use in case of CNC for removal of sliding between moving parts and stationary parts. If there is sliding for very slow motions there can be stick slip motion which will totally spoil the motions in the slides and guides of CNC machines, and this is called a recirculating ball lead screw nut mechanism. If I get a chance I will try to provide you with some notes on this one.

(Refer Slide Time: 22:52)



So, as time is short, I will summarily move on to some of the non-traditional material removal method. Non-traditional material removal methods are used when traditional methods are impossible to implement or the material of the workpiece does not allow the application of conventional methods where heavy forces would be involved or the shape of the work material is such or its size is such that conventional machining methods cannot be applied.

So, in these methods typically we find that material removal rate might not be very high but the feasibility of the process is the telling factor, it is the ultimate deciding factor. For example, if you take ultrasonic machining what does it mean? It means that instead of using a cutting tool or a workpiece there are some workpiece materials which do not allow conventional processes to be carried out, what are these?

Say I will give you an example glass, can you machine glass on the lathe or on the milling machine, it will fracture simply. So, if I want to machine glass or say some other say ceramic particle which is extremely brittle in that case I can instead of having heavy cutting I mean large cutting tool trying to remove material and incurring fractures, you make use of a very small cutting tool, now what is that?

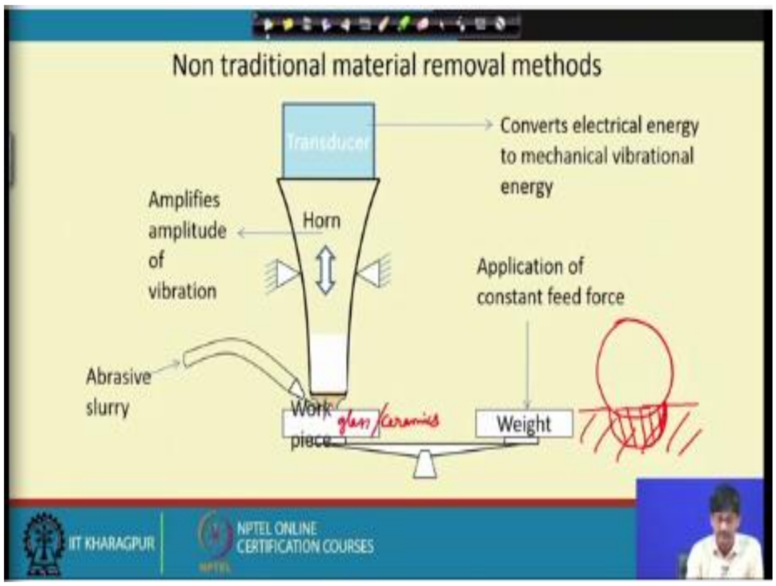
I can have abrasive particles used against the workpiece, so that fracture is minimized and material removal is made possible without some macro fracture lines existing on the workpiece. We will have a quick look at the method. Abrasive jet machining instead of ultrasonic machining depends upon vibrations, abrasive jet machining depends upon flow of abrasives carried in a gas jet and directed towards the workpiece.

Water jet machining and abrasive water jet machining take the help of water stream. So, these are electrical methods and apart from electrical sorry, these are mechanical methods where abrasives are used material removal is still by mechanical means but we can also have electrical processes. Electric discharge machining where we apply sparks in between work piece and the tool.

Electro chemical machining where electrolytic dissolution is made use of in removing material. Energy beam processes include laser beam machining where laser light which is light with a definite phase relationship with each and every photon particle carried in the beam. That kind of light is focused to a very small spot, so that a very high energy density is attained and this is used for removing material.

Electron beam machining where a beam of electrons would be targeted towards the workpiece surface and it will be focused by magnetic lenses or electrostatic plates to ultimately come to a concentrated spot where the electrons will be giving up their kinetic energy in the form of heat. So, in the same way these are some of the examples of particle beam, energy beam processes. So, let us go on to discuss these more detail.

(Refer Slide Time: 26:41)

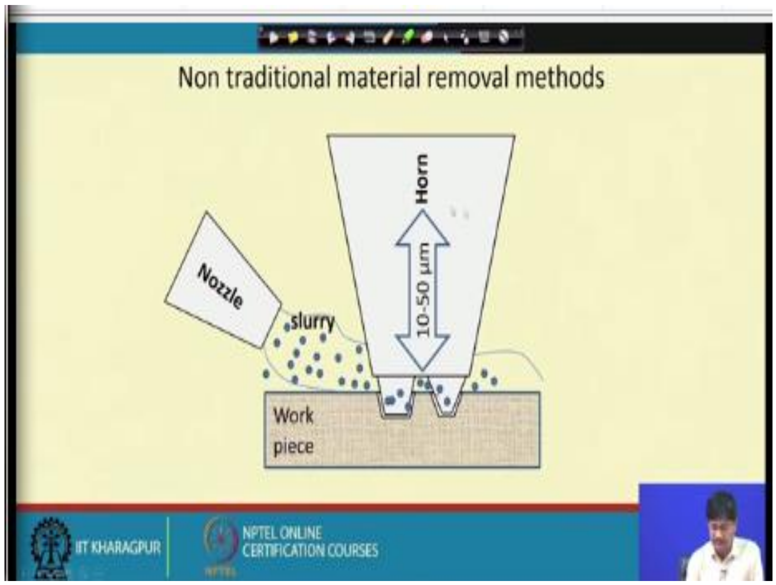


The ultrasonic machining method first of all has a transducer where electrical energy is converted to mechanical vibrations. These vibrations have their amplitude increased or multiplied by this device called a horn by its very shape. So, when the horn by breaks it creates a high amount of amplitude of say around 25 microns at its end where we fit a tool of a definite profile against the workpiece.

So, this is the workpiece which is typically a glass, I am just writing example is say glass, ceramics etcetera. So, on these we press this against the horn by applying a weight here, this is a common balance and we put some abrasive slurry. Some liquid say water carrying some abrasive particles like aluminum oxide, silicon carbide etcetera, very small particles of say 10 to 50 microns size and this vibration setup causes a hammering action.

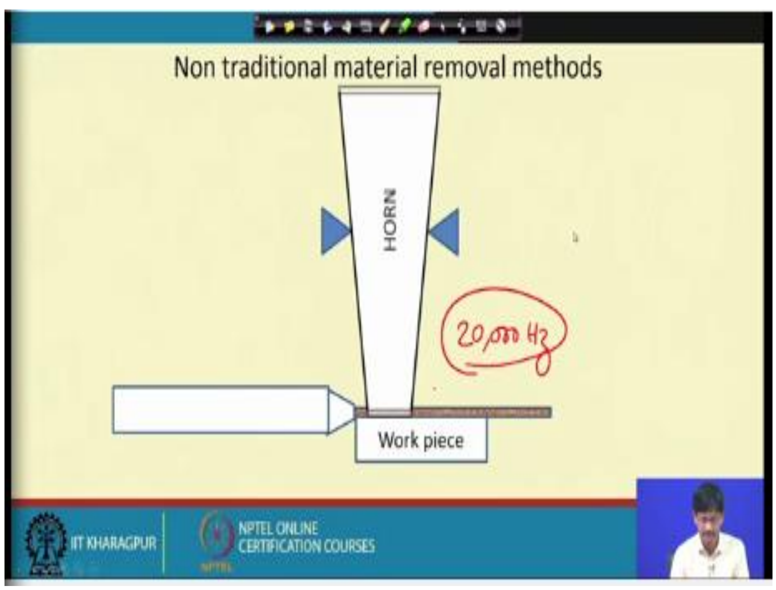
So, that the abrasives are impacted against the workpiece by this hammering action and they remove material typically this way. Abrasive particle idealized as a sphere, they hit the material of the workpiece this way and fracture takes place. We assume that fracture takes place in brittle material as a hemisphere getting removed, this particular part is removed as a hemisphere, this is the abrasive grit. So, let us move on to see further details on this process.

(Refer Slide Time: 28:44)



So, this is slightly magnified view, all the details that we discussed they are shown here.

(Refer Slide Time: 28:51)

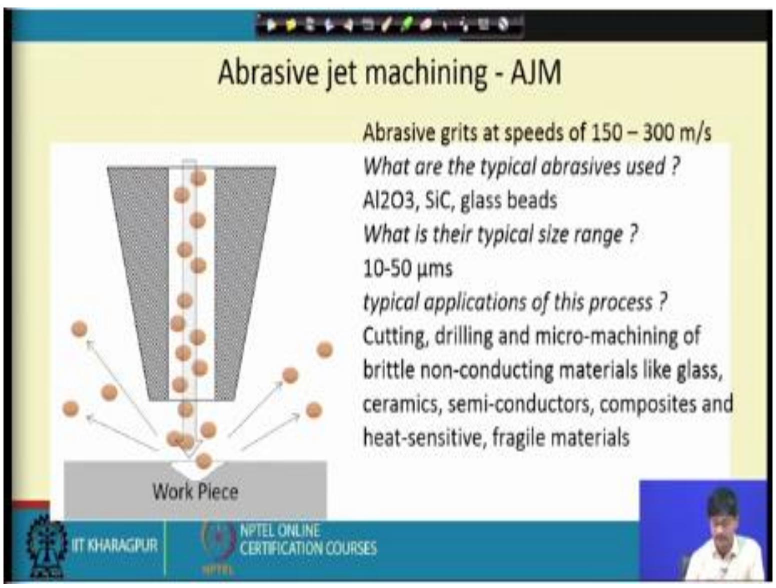


And this is how it operates; can you detect a very small amount of vibration of this tool? So, this is what happens and the frequency is even higher than what I have put in here, this is the abrasive slurry which came out. It goes on and on, it is put in here by a nozzle and this one is vibrating at say typically 20,000 Hertz per second, it is vibrating 20,000 times, so, so many impacts are taking place. And these are the abrasives which are put inside, put in between.

(Refer Slide Time: 29:36)

So, these are some of the impressions of those tools which we have used on USM on glass pieces.

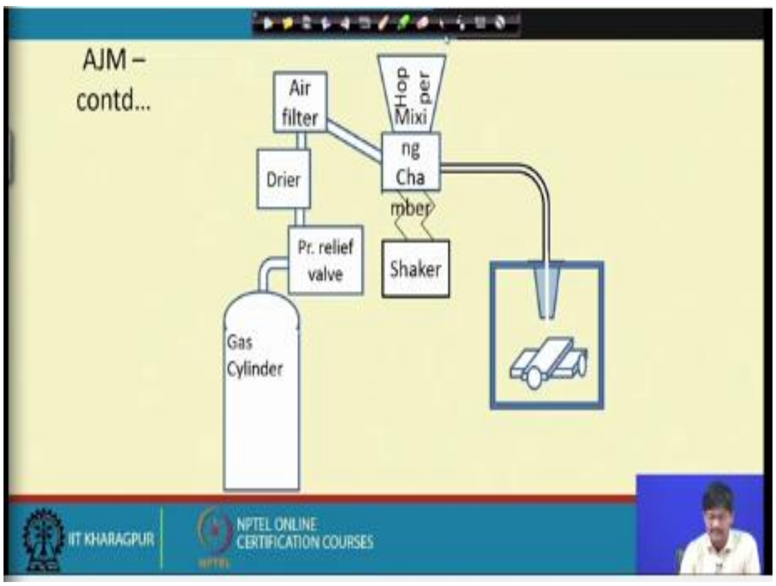
(Refer Slide Time: 29:53)



Abrasive jet machining, a nozzle here is shown to be throwing abrasive particles against the workpiece and what is the speed? Speed is 150 to 300 meters per second. And how are they carried? They are carried on a gas jet. What are the typical abrasives used? Al_2O_3 aluminum oxide, silicon carbide, glass beads, their size range is 10 to 50 microns, applications include cutting, drilling, micromachining of brittle non conducting materials like glass, ceramics, semiconductors, composites, heat sensitive fragile materials, so this is abrasive jet machining.

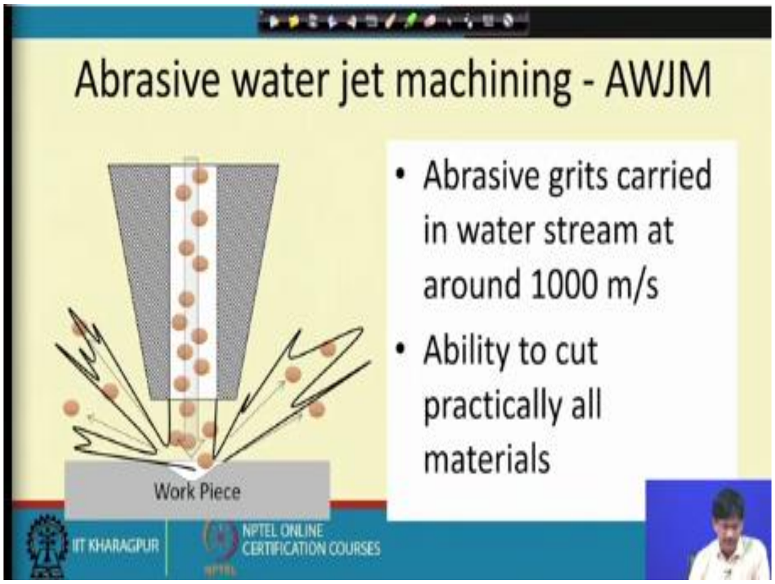
Abrasive jet machining one very common application is that suppose there is a pipe and internally there are some burrs sticking and creating some obstruction to some sort of flow which you intend through the pipeline. Abrasive jet nozzle can be put inside that pipe remove that burr (30:59) which is extending inside the pipe which other processes cannot practically carry out.

(Refer Slide Time: 31:13)



This is the setup of an abrasive jet machine which shows the simplicity of the process you simply need a gas cylinder. And from the gas cylinder there is a pressure relief valve, dryer, air filter etcetera to the mixing chamber where abrasives are put into the air stream. And out it comes through a nozzle and there is a workpiece which can be manipulated under the jet and whatever machining is required it can be obtained. However, this is restricted by the low MRR which is obtained in such a process.

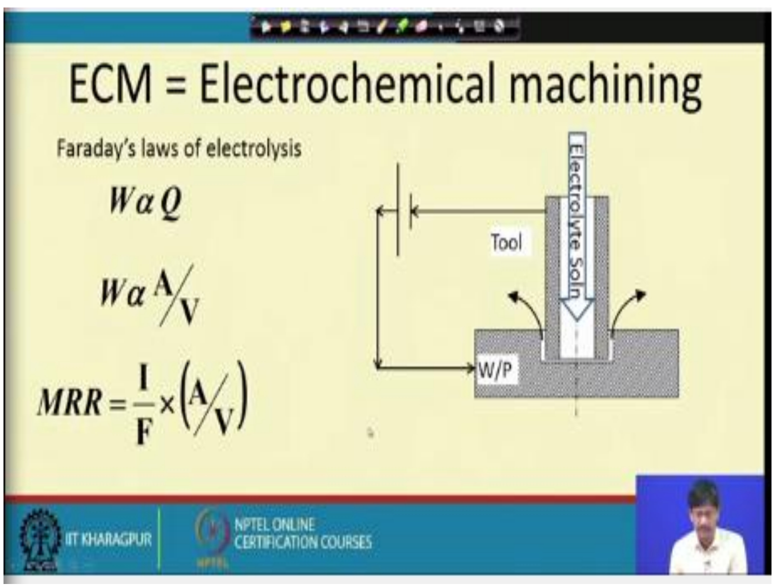
(Refer Slide Time: 31:52)



In case of water jet machining and abrasive water jet machining however it is much more versatile than ultrasonic machining and abrasive jet machining, in what way? The abrasives now coming out there are 1000 meters per second almost, and they have the ability to cut practically all materials, not only brittle materials. In abrasive water jet machining and laser beam machining both of them can cut practically all materials.

But laser beam machining has become much more accepted due to its versatility and also at its ability to cut very hard and tough materials. For hard and tough materials abrasive jet machining is not so appropriate.

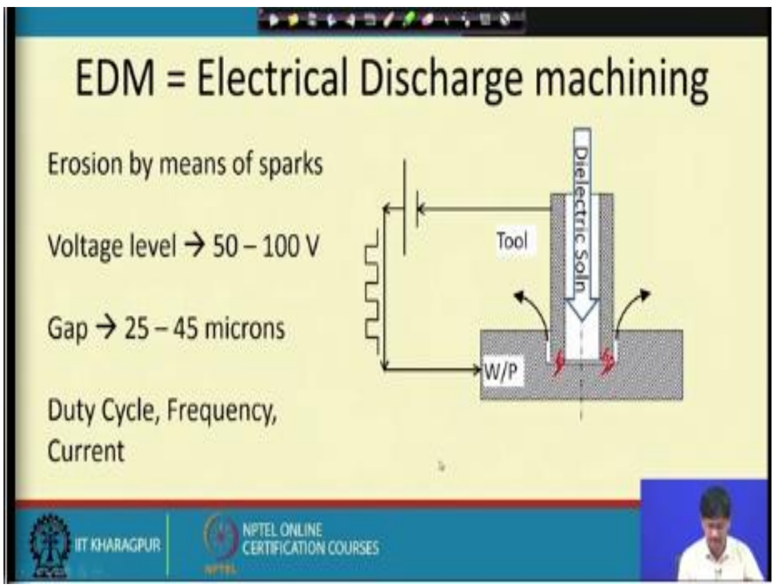
(Refer Slide Time: 32:47)



Electrochemical machining, it is developed on the principle of electrolysis. Weight dissolved or deposited at a particular electrode due to electrolysis is directly proportional to the total amount of charge passed, it is also proportional to the atomic weight by valency of the material being resolved or deposited and MRR that way is equal to once we remove this proportionality I by F, current by Faraday's constant into atomic weight by valency.

Electrolyte solution is coming in; this is the tool or a active electrode. And this is the workpiece, it is given anode connection and this is given cathode connection. And due to electrolysis as the tool is moving towards the workpiece, it selectively dissolves this portion of the workpiece, so that material removal will be achieved together with a certain profile being given to the workpiece.

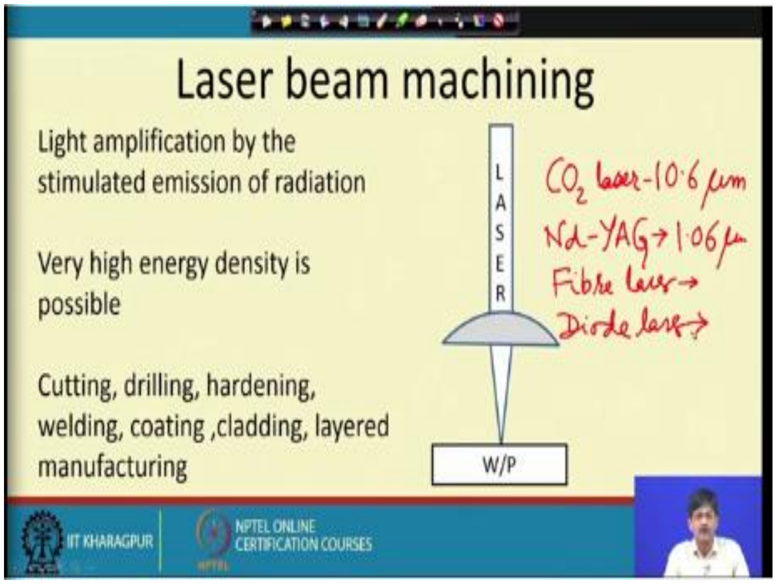
(Refer Slide Time: 33:56)



Electrical discharge machining is almost the same but the principle is completely different, the setup is almost the same. Here a dielectric fluid comes in and it creates in the gap which is created across this can jump through. So, if we have sparks jumping across this particular gap, it removes material. And ultimately when the tool is directed this way these sparks remove sufficient materials, so that the profile on the tool a conjugate profile is made on the workpiece.

These are specially applicable for materials which are conducting and even if they are hard material can be removed. Pulses are applied instead of continuous voltage to avoid arcing and also to provide some time for flushing out of the products of reaction because lot of material will be coming out as sludge.

(Refer Slide Time: 35:14)



So, here in laser beam machining what happens is a laser which is light amplification by the stimulated emission of radiation. Basically electromagnetic waves at a definite frequency with a definite phase relationship between different points will be focused by a lens and develop very high energy density at the point where it falls on the workpiece. This energy can be to the tune of 10 to the power 5 watts per centimeter square or even higher.

So, this can practically melt all known materials and hence it can be used for cutting, drilling, hardening, welding, coating, cladding, layered manufacturing etcetera. Laser is thus can be considered to be the most versatile of all the material removal methods which are known to us. And examples of laser include CO_2 laser the wavelength is 10.6 microns; it also includes the Nd Neodymium YAG, yttrium aluminum garnet laser which is at 1.06 microns.

And recently the fiber laser almost at the same frequency, the diode laser these lasers are coming up which are extremely versatile and they can be used for a number of applications. So, this brings us to the end of the discussion on CNC machining and non-traditional machining methods, thank you very much.