Mathematical Modeling of Manufacturing Processes
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Lecture - 13
Principle and Mechanism at Different Processes - 2

We have discussed the water jet machining processes. Now, we will try to look into that abrasive water jet machining processes. It is a combination of water jet machining as well as abrasive jet machining processes. So, to take the advantage of from both the processes and in this case it follows almost similar kind of principle what we follow in water jet machining and abrasive jet machining.

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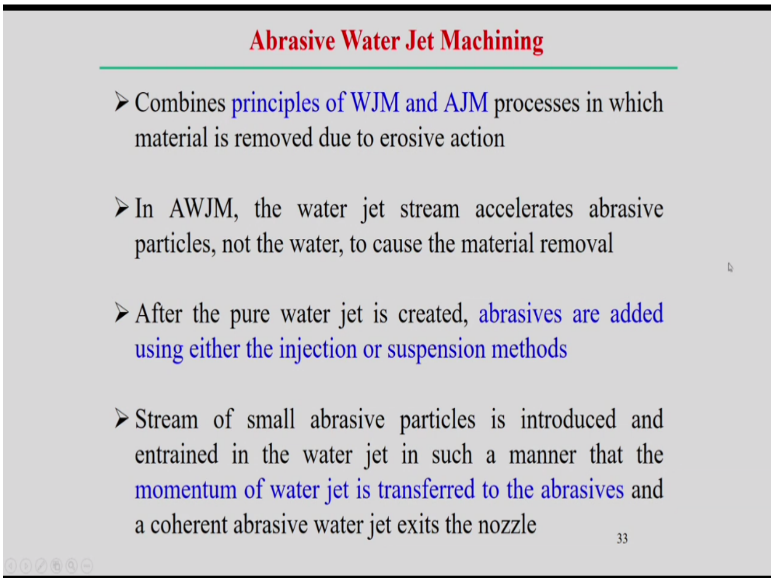

So, here the water jet actually accelerates the abrasive particles and then impact on the workpiece surface and then erodes the material. So, first actually water jet is created and then abrasive particles is add to the water jet such that it injected through the nozzle head and finally contribute to the erosion of the materials as a greater aspect as compared to the individual of either water jet machining or as compared to the abrasive jet machining process.

But in this case, the abrasive particles are introduced in such a way that we take the advantage of the movement of the water jet and then abrasive particles is actually introduced to the water jet such that momentum can be transferred to the abrasives and then it takes a final act on the surfaces.

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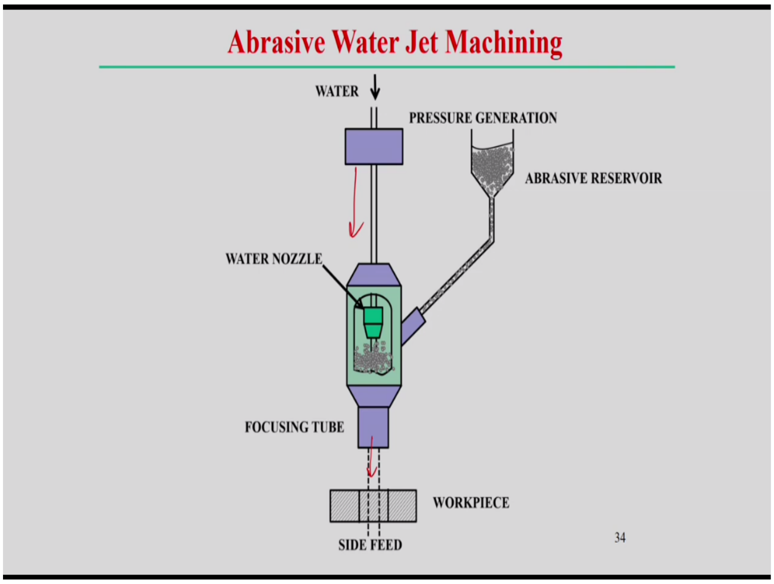

Here, we can see the schematic of the abrasive water jet machining process. So, water reservoir is there and then water comes from the reservoir and then there is a pressure generator through which the abrasive particles actually flows here and then water nozzle is here through once water comes out from the nozzles and then abrasive particles is added to the water nozzles and finally it comes out through this part and impact on the workpiece surfaces.

So, this is the typical, very simple configuration of the abrasive water jet machining. Here, you can see that the mixing of the water jet and the abrasive particle is a main component in abrasive water jet machining process.

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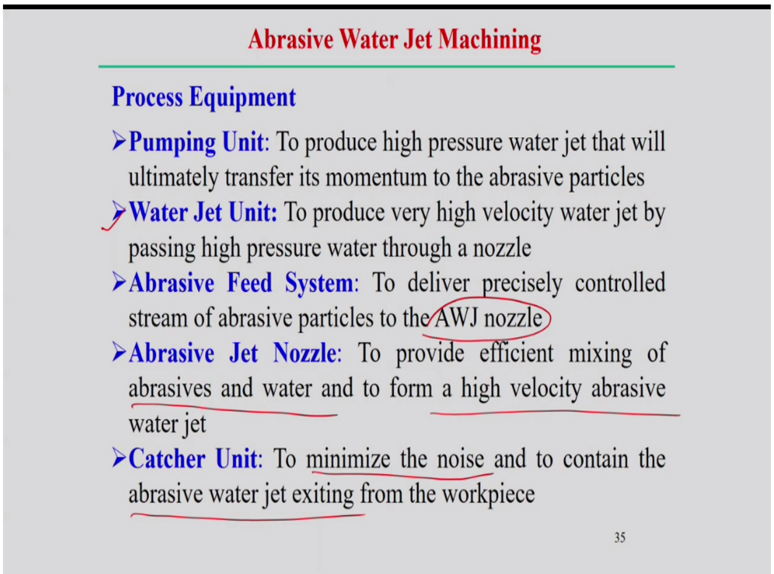

What are the equipments required for abrasive water jet machining process? We can see we have listed here also that first is the pumping unit to produce the high pressure water jet that actually ultimately transfers to its momentum to the abrasive particles. So, first have to pumping unit is required basically to create the high pressure water jet and then other unit is the water jet unit and very high velocity water jet bypassing creating the high pressure water and it comes out through the nozzle.

And then abrasive feeding system also part of the system is delivered precisely, the steam of the abrasive particles and that actually makes with the water jet and creates the abrasive water jet comes out through the abrasive water jet nozzle and abrasive jet nozzle, this is also efficient, abrasive jet nozzle also acts in such way that it contribute to the efficient mixing of the abrasives and water such that high velocity abrasive particles comes through the water jet.

And finally that catcher unit, catcher unit basically to dampens the high velocity of abrasive and water jet that unit after cutting actions and the main purpose of catching unit to minimize the noise and that actually neutralize the effect of the high velocity water jet existing from the workpiece. So, these are the typical units or components of the abrasive water jet machining processes.

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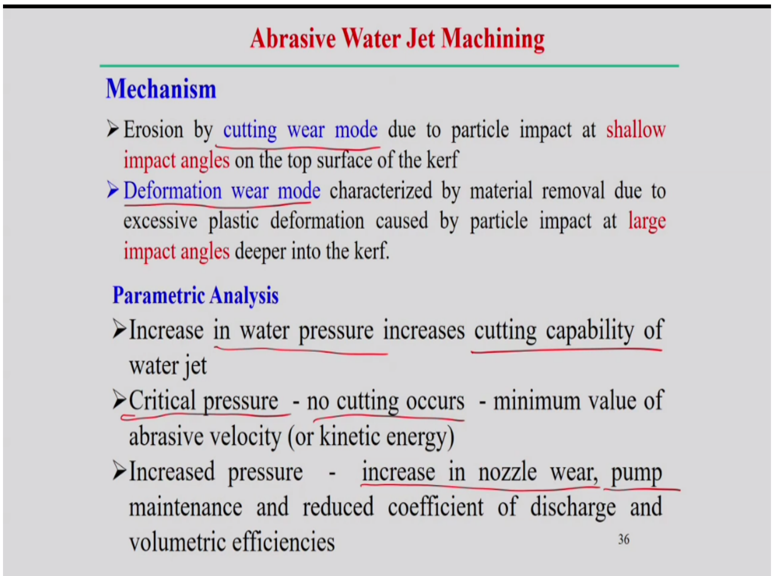

Mechanism if we look the abrasive water jet machining, it is a similar kind of mechanism water jet machining as well as the abrasive jet machining but basically erosion mainly happens on the two different modes; one is the cutting wear mode and that depends on the impact angle on the surface, other is the deformation wear mode.

So, in cutting wear mode, we can see the impact angle, the shallow impact angle we normally follow on the surface of the curve. In this case, basically wear mode simply cut the samples and in this case maybe in the cutting of the samples without much deformation of the samples but if the large impact angle is followed, in that case the deformation mode becomes more active in these cases.

So, depending upon the type of materials whether ductile type of materials, brittle type of materials we can follow what type of cutting mechanism should be active in abrasive water jet machining process. Maybe look into parametric analysis that means what we can change the parameter such that it will impact on the material flow or characteristic material removal rate for these processes.

For example, first we look into the water pressure. If there is an increase of the water pressure, definitely water pressure increases means jet velocity can be increases. So, jet velocity can be increases. That means otherwise the cutting capacity of the jet can be enhanced by simply increasing the water pressure. Second is that but there must be some amount of the minimum pressure to create that is called the critical pressure to maintain.

And below that there may not be any cutting occurs, so that minimum value of the abrasive velocity has to be followed and such that we should maintain in the system the minimum pressure that is called the critical pressure and above the critical if we increase if we follow the pressure much above the critical value, then what will happen? That actually increases the adverse effect in other way that enhances the nozzle wear.

Because the abrasive particles actually come through the nozzle and one of the serious problem in the abrasive jet machining is that the erosion of the nozzle. So, in that case, if we increase too much of pressure, then nozzle wear may be increases other way the pumping maintenance, reduce coefficient of the discharge and volumetric efficiencies normally reduces.

So, there must be some optimum range, some range of the pressure we need to follow such that we can get again the optimum effect of the maximum metal removal rate with minimum affecting on the nozzle wear and other parameters.

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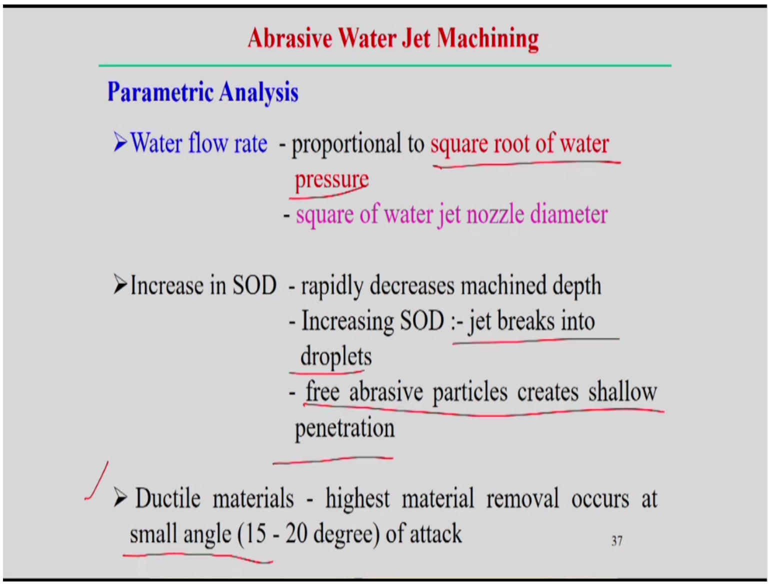

Water flow rate, parametric analysis can be done in that way that for example water flow rate, we need to maintain the water flow rate. It is basically proportional to the square root of the water pressure. It depends on square root of the water jet velocity nozzle. If you know the flow rate, water flow rate that means if there is increment of the pressure, the water flow rate will increase and at the same time if square of the water jet nozzle diameter.

So, if nozzle diameter becomes very high that means more, in that cases we can enhance the flow rate of the water can be increased but that does not mean that velocity can be increased. Other parameter is that stand-off distance, definitely the stand-off distance is one critical parameter that actually decides the surface basically the what we can surface profile and up to what accuracy we can create the exact surface profile that largely depends on the stand-off distance.

So, if we increase the stand-off distance, rapidly decreases the machine depth. That means stand-off distance becomes very high, so just the velocity is maximum just when the water comes out through the nozzle, basically nozzle tip the velocity becomes maximum, gradually the velocity actually decreases but increases the stand-off distance. Then, jet can break into the small droplets.

When there is a breaking of those jet droplets, then the erosion action is mainly by the abrasive particles. So, in that cases, the abrasive particles is the more responsible to remove the material from the workpiece. So, then free abrasive particles creates the penetration, that

that cannot be very depth because kinetic energy also decreases in these cases, so shallow penetration can be created if we increase too much of stand-off distance.

Otherwise, if we look into the parametric analysis, what type of angle we should follow in case ductile materials? So, in this case, the highest material removal rate is possible if we follow the small angle, angle of attack. Basically, in this case, the angle of attack through is from angle of attack with respect to the nozzle and the workpiece and position of the nozzles with respect to workpiece.

In these cases, the angle of attack is very less, that is more suitable in case of ductile material such that we can produce as much as possible the cutting action rather than only the deformation action.

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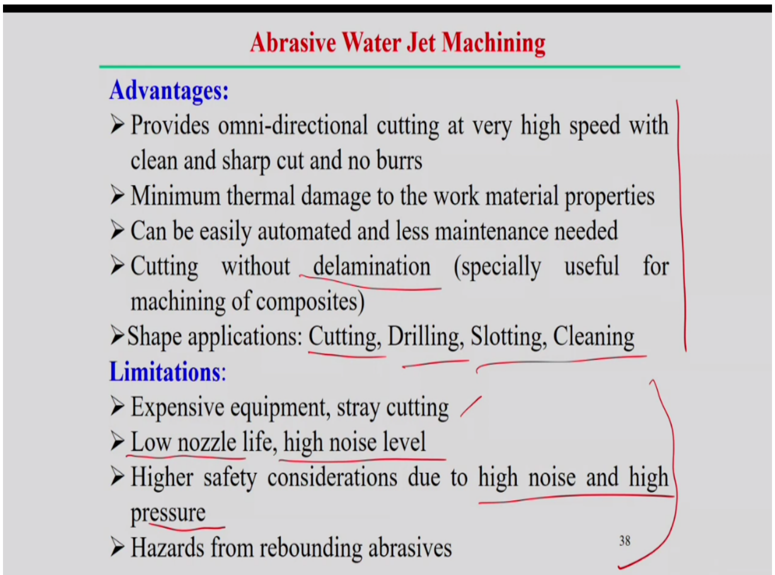

What are the advantage, disadvantage for abrasive water jet machining, you can see are listed here. If you see, it is a very cutting high speed with clean and sharp cutting and no bars can be produced using the abrasive water jet machining, minimum thermal damage because other way also when you sink the water is used, water is basically act as this heat sink in this case, so thermal damage can be minimized in abrasive water jet machining process.

Can be automated easily and low maintenance needed and this is very general comments regarding the advantage of this process but cutting without deformation sorry not deformation it is a delamination, that means delamination means not much change in the volume of the workpiece material. So, that can be useful for machining of the composites, so in these cases that are advantageous.

And this delamination is minimized when the cutting action becomes very rapid. So, that is normally observed in case of abrasive water jet machining. Other cases, safe applications for example different types of the cutting, drilling, slotting and cleaning and the different types of the processes we can use the abrasive water jet machining process but limitation is it is a little expensive equipment.

Stray cutting can also be possible in the certain cases. The most serious problem in this limitation of this process is the limited life of the nozzle that is the one and second is the high noise levels can be created that is why we need the catching unit to dampen the noise or to reduce the noise and we need the effective design of the caching unit in that case. Higher safety consideration due to high noise and the high velocity and high pressure we maintain normally observed in this process, so safety requirements is required.

And hazardous from the rebounding abrasive, the possible issue is that the rebounding abrasives one the very carefully handle the rebounding effect of the abrasives during this process. So, that we have to be, we need to look into these aspects, that is we can say typical limitation of all these processes. So thank you very much for your kind attention.

So, next we will try to look into the other types of the non-conventional machining processes. Now, will look into the other types of the machining processes; one is that electrochemical machining process, one of the most important the non-conventional machining processes.

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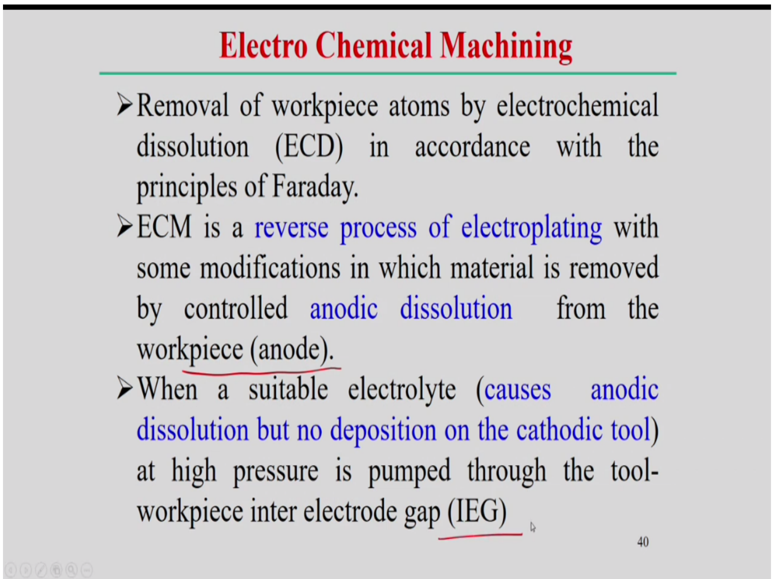

Here, the removal of the workpiece atoms by electrochemical dissolution normally happens in accordance following the Faraday's principle but it simply is a reverse process of the electroplating with some modification in which the material is removed by controlled anodic dissolution from the workpiece. So, workpiece is considered as an anode in this case and then how the workpiece or may be anodic materials dissolution happens.

We follow this principle such that it is a reverse process of the electroplating. So, in that principle, the electrochemical machining process has been developed. So, we need definitely in this process, there is a requirement of the one kind of electrolyte that actually cause the anodic dissolution but no deposition on the cathodic tool. So, we have heard the deposition, this is dissolution and avoid deposition of the catholic tool such that after dissolution we just remove the material using the high flow of the dielectric fluid here.

So, in these cases, the high pressure is pumped through the tool workpiece inter electrode gap and that gap is very important here.

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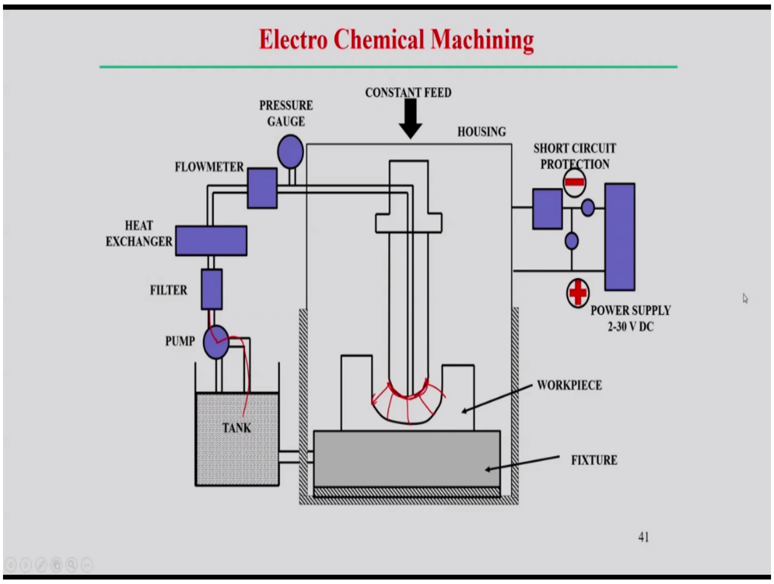

So, look into the schematically here, what is the electrochemical machining process, here this is the unit, so tool having certain shape and of course if you want to create that kind of the shape in the workpiece accordingly we need to choose the shape of the tool. So, then workpiece and such that uniform gap is maintained between the workpiece and the tool. So, similar shape of the tool we can replicate using this process.

Now, what are the units here? The constant feed is given to the tool material such that by constant rate the metal removal can happen here. The flow meter to regulate the electrolyte, pressure gas to maintain the pressure and heat exchanger also they are filtering. So, from tank is pumping and then filter and then if heat exchange is required to reduce the temperature or maybe to control the temperature.

And then flow meter regulate the flow rate of the electrolyte and constant feed is given to the tool and then workpiece is connected through that circuit, then the power supply normally use the DC voltage supply and then using this circuit this normally this is followed in case of the electrochemical machining process.

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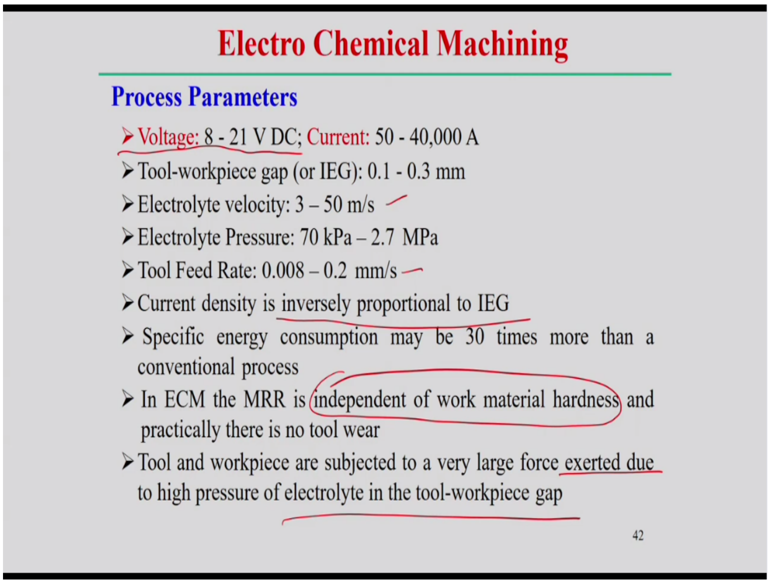

What are the process parameters normally followed here? In this case, that voltage normally 8 to 21 volt, if you see the voltage, normally DC current is used; current can be used from 5 to 40,000 ampere. Tool-workpiece gap or inter electrode gap can be 0.1 to 0.3 millimeter, so that gap is very small in these cases. Electrolyte velocity, basically high-velocity electrolyte can be passed through that gap.

This can be 3 to 50 meter per second and the pressure also high pressure also created and 7 kilopascal to 2.7 megapascal that high pressure electrolyte actually passes through the gap between the workpiece and the electrolyte and the tool feed is follow very low tool feed. If you see the feed rate is very small, it can be 0.008 to 0.2 millimeter per second only and current density follow in these cases is dependence normally inversely proportional to the gap between the workpiece and the electrode.

But in this case, specific energy consumption becomes very high, almost 30 times more than that of the conventional process. Of course, electrochemical machining process, the metal removal rate is independent of the hardness of the work piece material and practically there is no tool or like in other welding other processes, for example if jet machining or abrasive water jet machining processes.

And of course, in certain cases with respect to the electro discharge machining processes. So, in that case, it is advantageous to learn workpiece is subjected to very large force that is the only thing because high pressure have to be created such that electrolyte can pass through using that such that it can carry the dissolution material. So, high pressure to electrolyte in the tool-workpiece gap.

So, that is the only subject, force is basically involved in that is subjected to the workpiece and the electrode materials. Other the main if you look into the model aspect of the electrochemical machining that main aspect is that at any hardness material can be machined using this process. So, that is the main limitation in case of the conventional material machining processes.

Here, we need to the material removal rate or efficiency of the process more or less depends on the hardness of the workpiece, accordingly we need to choose the cutting tool also but in these cases that is independent that is the main advantage of this process.

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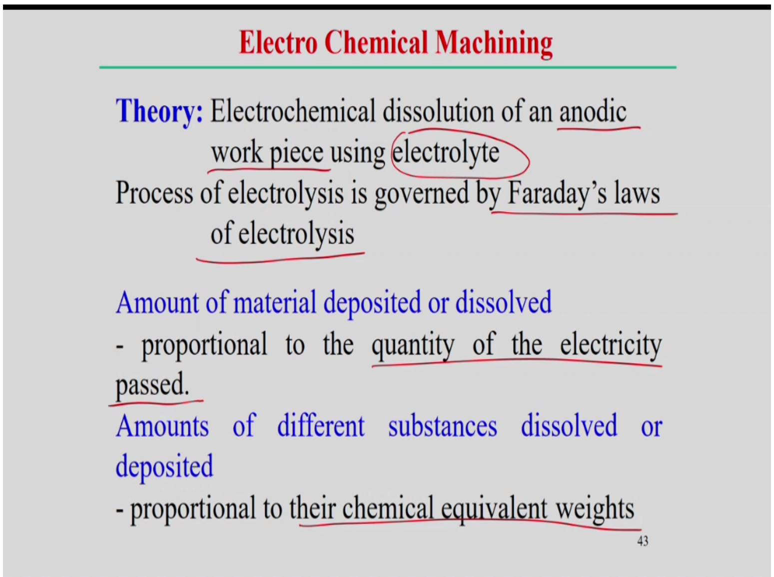

Theory; electrochemical dissolution of an anodic workpiece using the electrolyte, so anodic workpiece using some electrolyte, some electrochemical dissolution happens such that process of electrolysis here actually governed by this Faraday's law of electrolysis. It is followed by this law in principle and then removes the material. Therefore, amount of the material if we look into that principle of the electrochemical machining process, the amount of the material actually dissolved or deposited.

Basically, in these cases dissolved but not exactly deposited because after dissolving we use the high-pressure electrolyte and the high velocity and high pressure electrolytes such that it carries the dissolved material but anyway that amount of the deposited or dissolved material dependence is proportional to the quantity of the electricity passed. What is the amount of the electricity passed during the process?

The amount of the material deposited depends on that and of course other cases for example different alloying element, the amounts of the different substance dissolved or deposited, it also proportional to the chemical equivalent weight. So, it depends on the chemical equivalent weights of the workpiece material we are using here.

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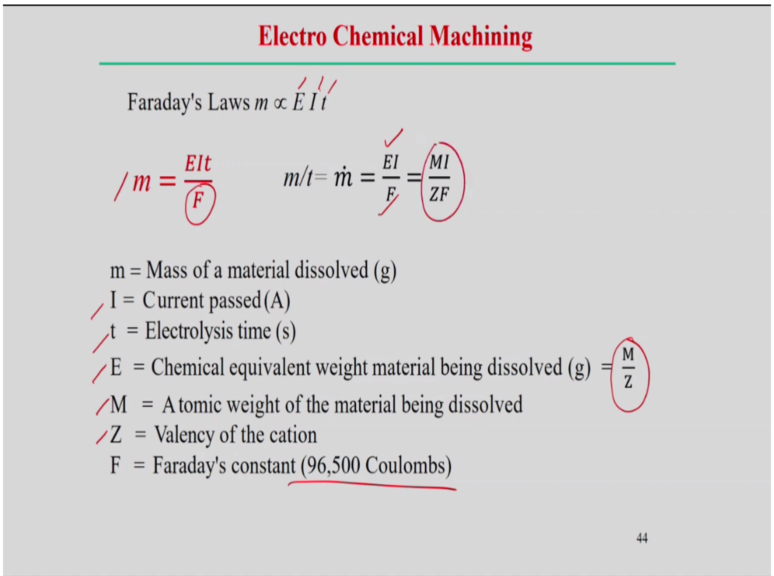

Now, in general mathematically, we can represent the Faraday's law, m is mass of a material dissolved that depends is proportional to the E, E means the chemical equivalent weight of the material being dissolved okay. This can be represented by M/Z where M is the atomic weight of the material dissolved and Z is the valency of the cation, so it depends on this. Second, the current passed, what is the amount of the current passed? The ampere, in terms of ampere it depends on that and t, t is the electrolyte, electrolysis time.

So, electrolysis time it depends on these things. So, basically M is proportional to the E*I*t. Now, is the mass of the material dissolved? So, when you remove the constant of proportionality then we need to introduce the F that is called the Faraday's constant. It is given that 96,500 Coulombs. So, this is the expression of the mass of the material dissolved using Faraday's principle here.

Now, if we say the rate of the mass dissolved, so that means is simply M/time t, it is a rate depends on the EI/F and that can also be if we replace the E in terms of M/Z the atomic weight of the material and the valency of the cation, then we can simply represent MI/Z*F in this case.

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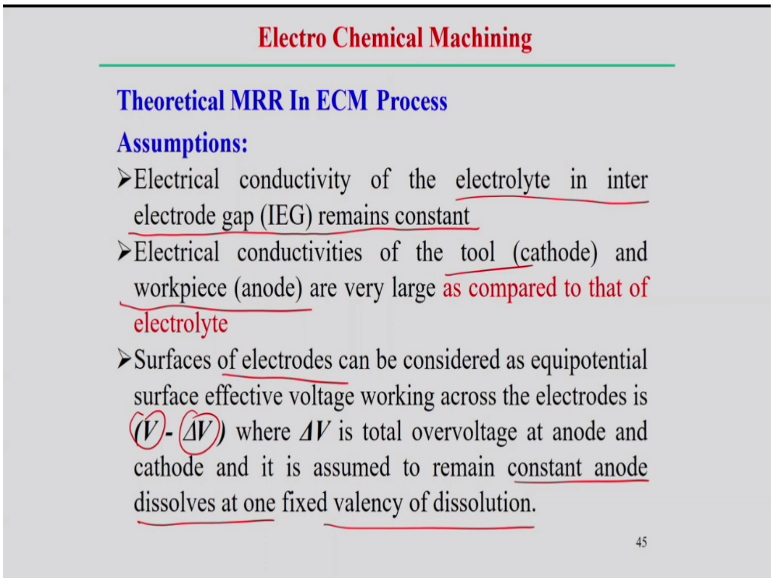

Now, what are the assumptions to calculate the material removal rate in case of the electrochemical machining process? First is the electrical conductivity of the electrolyte in the gap remains constant that is the first assumption. So, we assume that conductivity remains constant using this gap, that gap, actually that surface which surface, basically the profile we want to create between the workpiece.

And the similar property we follow in case of the electrode and that surface is basically assuming the same conductivity exists throughout the surface. Then, electrical conductivity of the tool material, cathode and the workpiece are very large as compared to that of the electrolyte. So, electrical conductivity of the tool material is actually tool and the workpiece is very high as compared to the electrolyte we used in this case.

Surface of the electrode can be considered as the equipotential surface effective voltage working between across the electrodes. Basically, we assume the equipotential voltage although the equipotential voltage exists between this and the surfaces of the electrode such that we assume there is a change in the voltage delta V. So, there is equipotential voltage say for example it is V if there is a change in the voltage V.

Over voltage may be in delta V at anode and cathode and it is assumed that it remain constant, anode actually dissolves at one fixed valency of the dissolution. So, in this case, with the applied voltage between this electrode and the workpiece such that we introduce some, there is a change of the voltage in the delta V. Then, what will happen, we can explain the phenomena of during this process or basically transient phenomena during the electrochemical machining process.

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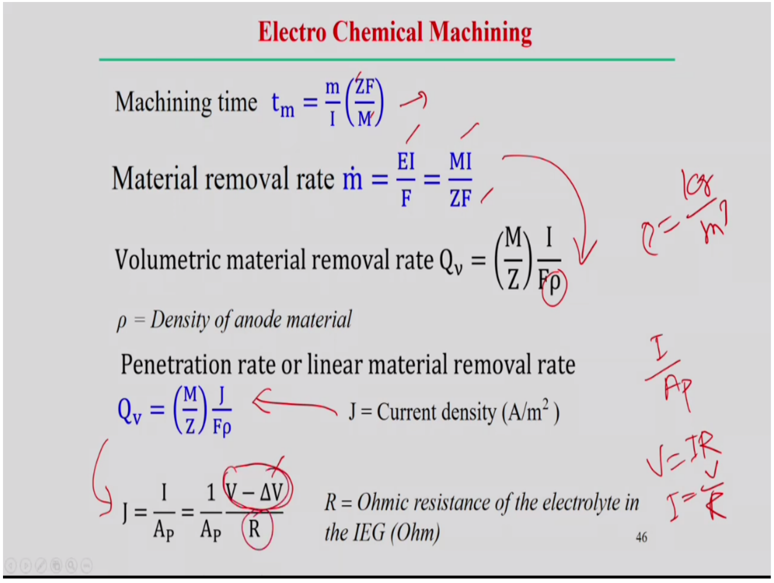

So, here we can estimate the machining time, this is the machining time can be like that if we go back to this formula that m this one, so here you can estimate the T=maybe mF/EI, such that similarly mF/EI, E can be represented Z/M. So, this is the machining time can be estimated here in this case. Then, material removal rate already estimated EI/F or MI/ZF, that we estimated the material removal rate in this process.

Volumetric material removal rate can be represented by M/Z 1/F, so in this case we introduce the density. So, we know the density of the anode material density we normally use the mass per unit volume. So, either we can use the material removal rate that means mass per unit time or material removal rate the volume per unit time, volumetric material movement rate so it is just simply conversion from mass to volume just by introducing multiplying the density of the material.

Now, penetration rate or linear material removal rate basically what that can be estimated from this thing by introducing the current density. So, current density is simply, measure of the current density is the current/area and such that we can estimate what is the current density, we can estimate the current density in this case. So, penetration rate or linear material removal rate here in this case, we can introduce in terms of using the current density value.

So, now obviously J=simply I/Ap, I is the current here and Ap is probably in these cases the cross-sectional area. Now, I can be represented that so we know the voltage equal to the current into resistance. So, I can be replace the voltage, so we assume there is a voltage potential difference to the applied voltage and there is a potential, some voltage can be consumed here that the delta V in this process.

So, the existing potential difference V-delta V and then I can be represented V/R here in these cases, so this is the voltage and this is the resistance. So, that is why we can estimate the current density.

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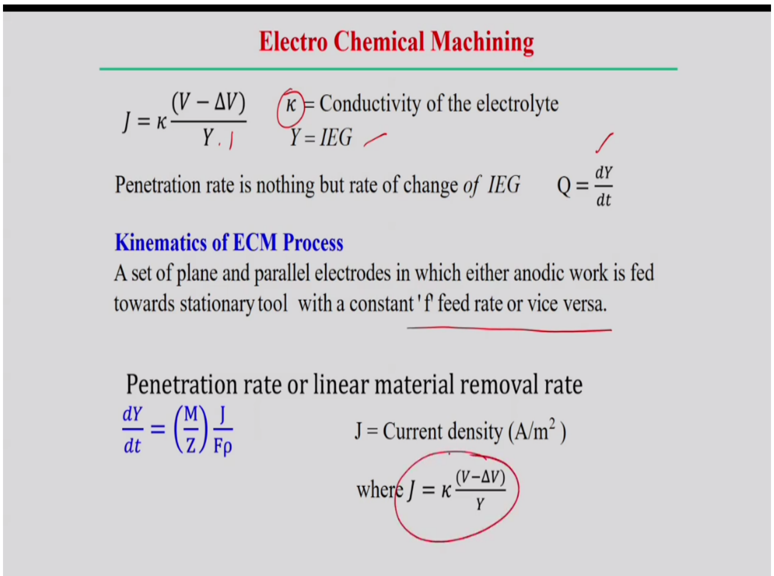

Then, current density can also be represented in terms of the other way also that conductivity of the electrolyte here, we say kappa basically conductivity of the electrolyte here and then Y=inter electrode gap in this cases but in these cases J=electrical conductivity and this Y*gap but in these cases when we estimate the linear movement of the electrode and that we estimating the area, the gap Y and other dimension we take the unit dimension.

Such that it can be represented by this way what say for example Y*1 the unit dimension. So, that it can be represented in terms of the current density. So, now penetration rate is nothing but the change of the inter electrode gap. So, inter electrode gap, the gap between the workpiece and electrode and the transient change of this gap can be represented by change of this gap with respect to time.

So, that dY/dt is basically we define that penetration rate the change of the inter electrode gap. Now, if we look into the kinematics of electrochemical machining process, we say assume that set of the plane and parallel electrodes in which parallel electrodes basically in which anodic work is fed towards the stationary tool. So, we assume that and workpiece is moved towards the stationary tool.

And then as F where F is the feed rate and vice versa also that vice versa in the sense we can assume this one workpiece is stationary and tool is feeding to the workpiece or other way also, keep tool constant and workpiece is more towards the tool with the feed rate, specific feed rate. Then, penetration rate or the linear material removal rate can be expressed as dY/dt and M/Z*J/Fp here and this J is the current density where J also can be represented as this one.

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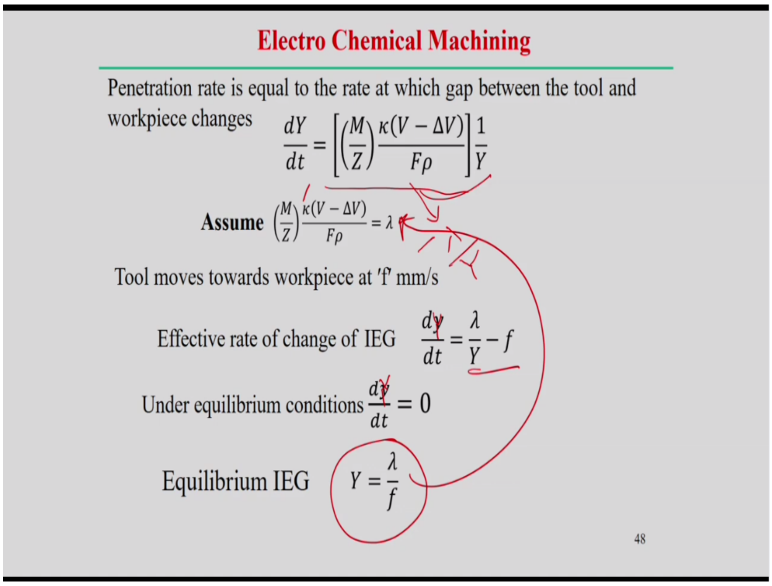

Now, if you replace J here, then we can find out the penetration rate is equal to the rate in which the gap between the tool and the workpiece. So, dY/dt we just simply replace the value of the J here. So, J here and we can find out that it can be expressed in this way the 1/Y and assume that this quantity is equal to lambda. So, tool moves towards the workpiece F millimeter per second for example.

Then, the effective rate of the change of the inter electrode gap dY/dt, so I think it should be Y. In this case, it is a, it can be represented by that this is by lambda so that total is the lambda/Y and we introduce that also tools movement or either workpiece relative movement between the tool and workpiece by some feed rate F, then it can be modified lambda/Y-F.

Now, at equilibrium condition dY/dt=0 at equilibrium inter electrode gap which can be represented Y=lambda/f.

And if we see the expression of lambda is this one, so it depends on the material properties M/Z, f is a constant density and this is also material property and existent potential difference between this effective potential difference that actually maintained at the inter electrode gap. So, from here if we know all these parameters, we can estimate the at the equilibrium condition what is the inter electrode gap in this case.

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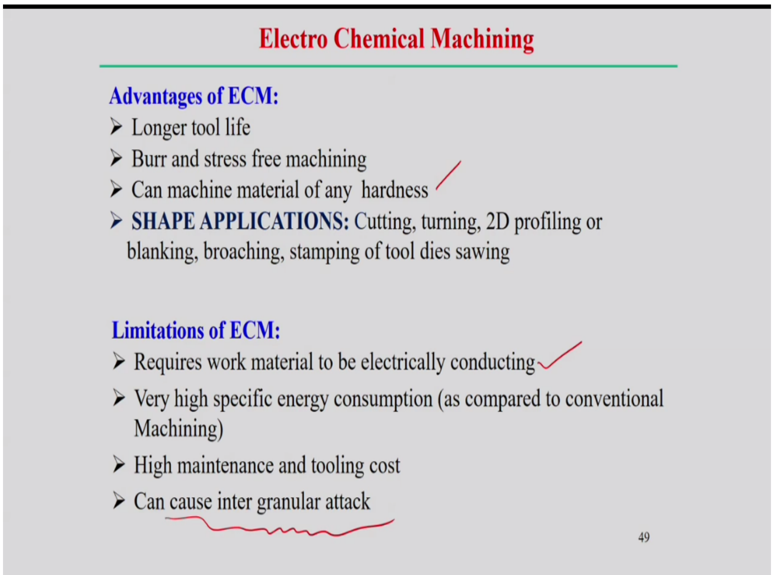

Now, what are the typical advantages of electrochemical machining, we can see the tool life is very longer tool life as compared to the other non-conventional machining processes. Of course, it is a stress free machining process, any hardest material can be used for this process and shape application, different type of the complicated shape can be generated. Cutting, turning, 2D profiling, blanking, broaching, stamping of the tool dies that different types of the shape can be obtained using this process.

But what are the limitations? First limitation, that means material should be electrically conductive that is the one limitation of this process, so but very high specific energy as compared to the may be more than 150 times, high maintenance and tooling cost also required but in metallurgical aspect grain, intergranular attack may also happen during this process. That is the one limitation of the electrochemical machining process.

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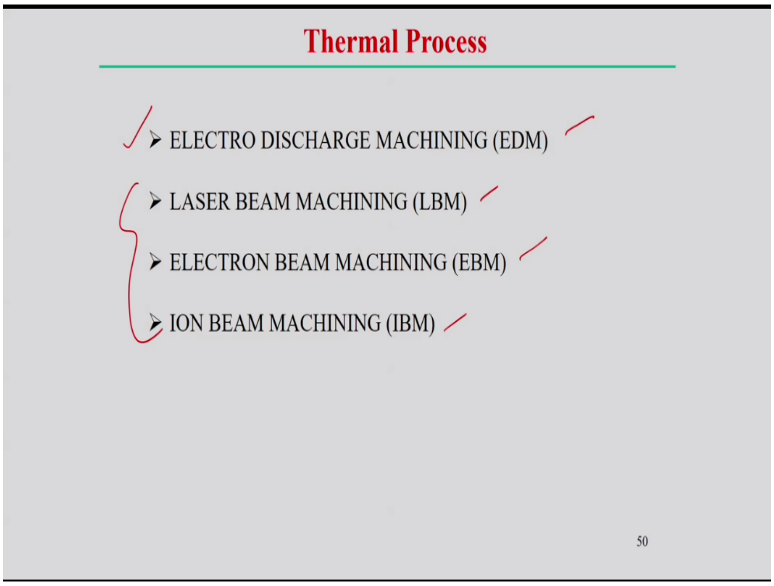

Now, if we look into the non-conventional machining process but under the category of the thermal processes, there are 4 different types of the processes; one is the electro discharge machining process, laser beam machining, electron beam machining and ion beam machining. These are the mainly 4 processes or maybe plasma machining process also exists that is under the category of the thermal processes.

So, out of this will try to look into details the electro discharge machining process and just overview of the other 3 processes we will try to cover in this case.

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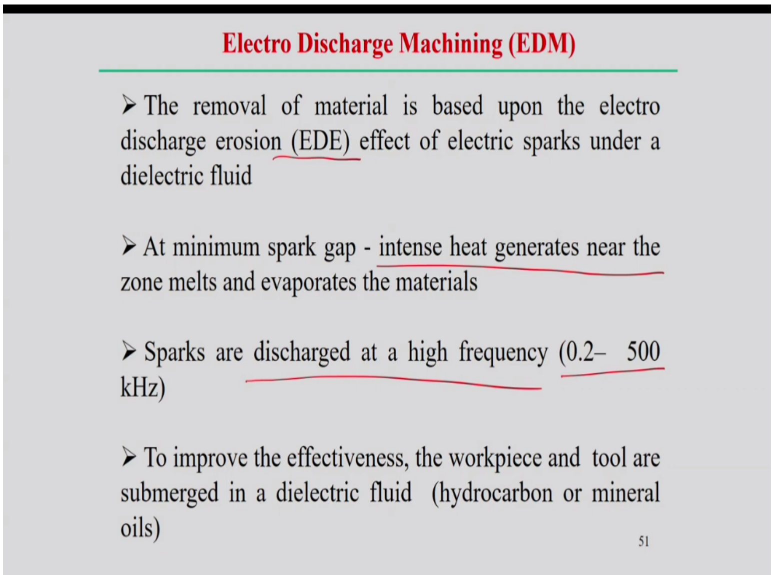

Now, electro discharge machining process; in this case the removal of the material is based upon the electro discharge erosion EDE, erosion discharge erosion effect by creating some kind the electric spark but that spark acts under the dielectric fluid in this case. So, therefore minimum spark gap is required whenever wherever the minimum gap exists in that case that creates the sparks between these two points between the tool and the workpiece.

And that at this point, intense heat actually generates near the zone where it melts and basically it directly evaporates the material in this part and of course in this case, sparks are discharged at very high frequency, so discharging sparks is around 0.2 to 500 kilohertz, in that range the frequency will normally follow in case of electro discharge machining process and of course to improve the effectiveness, workplace and tools are basically merged in a dielectric fluid.

And that dielectric fluid is normally passes through the gap between the tool and the workpiece at the high pressure such that it can carry erode or eroded material.

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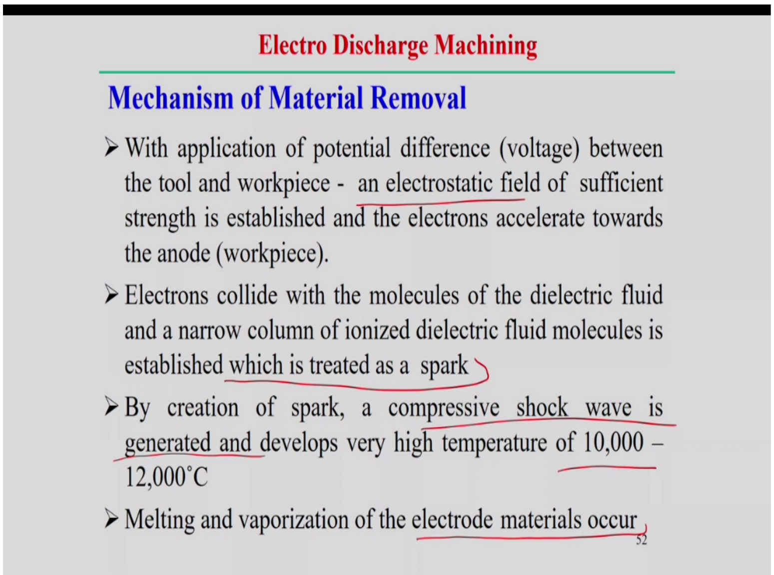

Mechanism, if you see mechanism of the material removal in electro discharge machining process, we can see the voltage between the tool and workpiece is basically applied in these cases and that actually create the electrostatic field and that electrostatic field is sufficient strength is established such that electrons actually accelerated towards the anode or maybe in these cases anode is the workpiece.

So, once electrodes collide with the molecules of the dielectric of course in between there is a dielectric fluid. So, once electrons actually collide with the dielectric fluid, they creates the narrow column of the ionized dielectric fluid molecules and then that narrow gap is trying to establish the spark, that spark is basically responsible for the erode of the material but this spark by the creation of the spark, a compressive shock wave is actually generated.

And that develops is very high temperature normally 10,000 to 12,000 degrees centigrade that temperature normally generated between this gap and then finally melting or evaporation of the electrode materials, electrode materials occurs as well as the workpiece material. So, in that sense, the wear of the tool is more serious problem in case of electro discharge machining process apart from the removing of the workpiece material.

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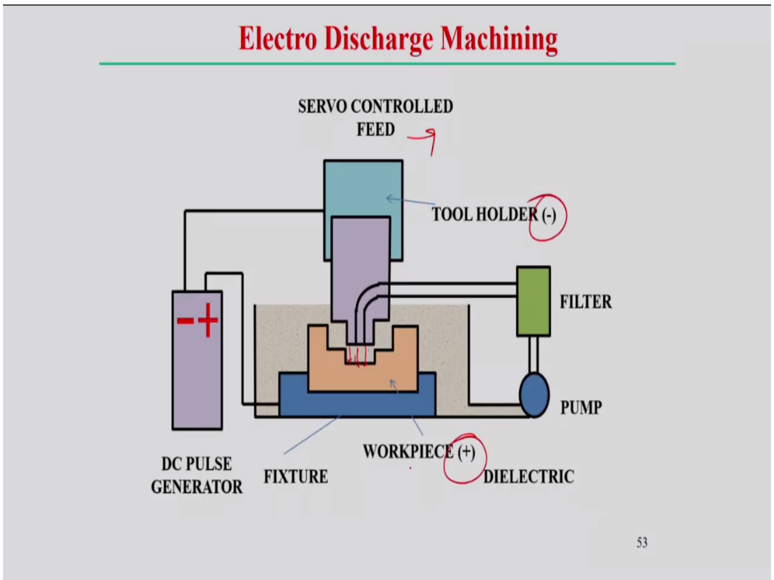

So, if you look into the unit that servo controlled feed system is basically to control the gap between the workpiece and the electrode and there is a dielectric fluid actually passes through that and of course dielectric fluid recirculate pumping, then filter and then that dielectric fluid again passes through the electrode and to the workpiece and then gap is maintained between the electrode and the workpiece.

And that gap actually controlled by the servo control feed system that basically that feed rate is controlled by this mechanism, fixture workpiece is given and then if you normally workpiece is connected to the positive side in the circuit and the other tool is basically is the negative and workpiece is positive here in these cases, DC pulse generator because we need to apply the current, some pulse current is required in these cases.

Or basically pulse generator is required to supply the high frequency or to create the high frequency spark between the workpiece and the electrode.

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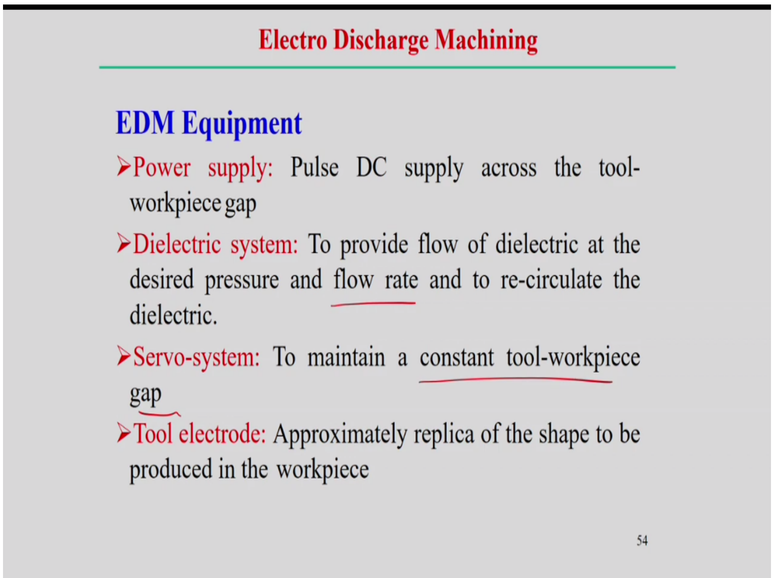

Equipment; simply power system is required power supply, DC power supply between the tool and the workpiece gap is required. Dielectric system is also required to control the flow of the dielectric fluid and basically to filter the dielectric fluid and with the maintain certain pressure to flow the dielectric fluid and of course pressure as well as the flow rate and of course recirculation is also then necessary in these cases is followed for the dielectric fluid.

And servo-system simply control the constant tool-workpiece gap, basically it maintains the gap using the servo-system and tool electrode approximately replicate of the shape to be produced in the workpiece. So, similarly what will the electrochemical machining process here also, what are the shape of the workpiece is required with the tool also, follow the simple replication of the workpiece to create that kind of the geometry on the workpiece.

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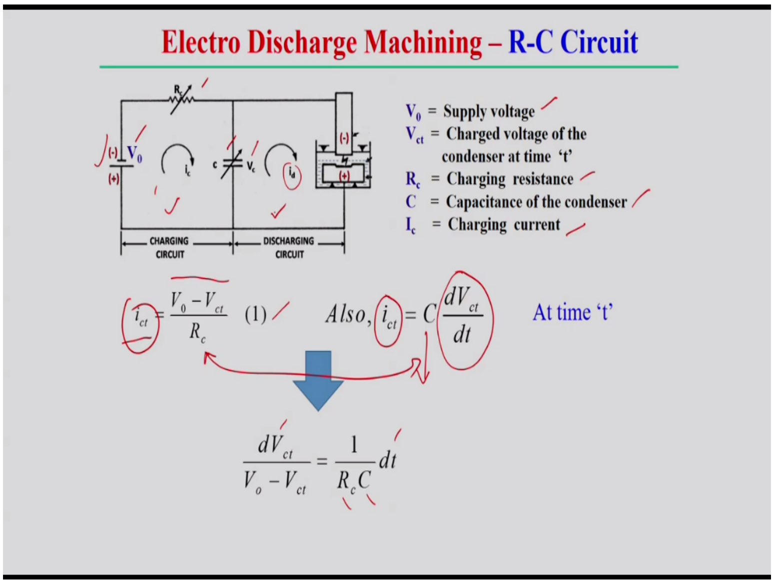

Now, we look into the RC circuit in the electro discharge machining process. We carefully look into that circuit diagram of electro discharge machining process, here we see that V0 is the input voltage supply here that the charging circuit and then in the charging circuit this is the charging circuit and this is the discharging circuit.

So, in this case, voltage supply V0 is the voltage supply if we look into that and Vct is the charged voltage of the condenser at time t, so here charged voltage of a condenser at time. Actually, the t denotes the respect to the transient phenomena and that is limited as a particular instant of time t, so that is why we mention here Vct charged voltage of the condenser at time t.

Rc is the charging resistance here in these cases, so here Rc is the charging resistance. C is the capacitance of the condenser, so C is the capacitance of the condenser here. So, that condenser helps for the discharging unit and Ic is the charging current here. If you see, the Ic is the charging current whereas Ic is the charging current, Id we can say the discharging current.

Say condenser actually units and then condenser actually charged with the supply voltage and with having certain charging resistance all these things. Now, if you look into the charging circuit and discharging circuit in this case, here you can see that what is the charging current at time t. Charging current at time t can be represented also that V0 is the supply voltage-Vct, Vct is the charging voltage at time t sorry Vct is the charged voltage, charging voltage to the condenser at time t.

So, this is the potential difference and then between these two and the potential difference between these two and divided by what is the resistance of the charging circuit. So, then current equal to this way we can represents what is the charging current sorry what is the Ic charging current in this case. Similarly, the charging current can also be looked into other way also.

The looking into the capacitance of the condenser, so C is the capacitance of the condenser and corresponding what is the change of the charged voltage of the condenser. So, change of the voltage of the condenser with respect to time. This is elemental from and then multiplied by the capacitance of the condenser that actually presents that charging current at time t. So, both represents the charging current at time t.

Now, if we equal these two components, then we can reach this elemental equation that dVct/V0-Vct=1/RcC*dt, so RcC defined as the variable quantity, t is the variable quantity. Basically, we can try to estimate what is assuming the charging voltage as a function of time and we try to establish this relation in terms of the other parameters. So, once we know this elemental equation, we can integrate it.

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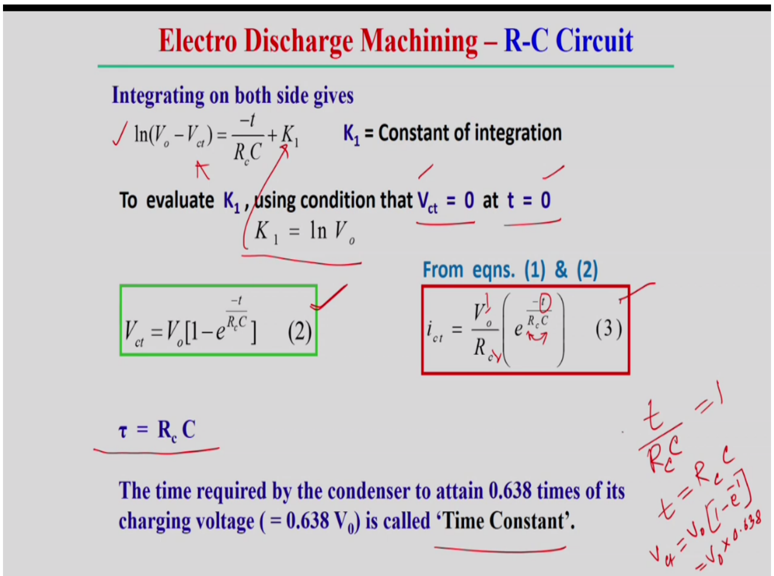

And from the integration, we can find out both the sides, we are going to find out this expression by integration. So, the K1 is a constant of the integration but K1 need to find out by using some kind of initial condition probably you can find out that at time t=0 basically charging voltage was 0. So, from these initial conditions, we can find out K1 equal to this value, so we just put Vct=0 at t=0 this equation.

And then constant of integration can be found out, K1=ln V so once we put K1 value here then we can reach this kind of expression. So, we can Vct is charging voltage=V0 what is the supply voltage*1-e to the power –t/RcC. So, it is basically changes, there is a change in this case, the charging voltage depends on the, it is a transient phenomenon, it depends on the t and initial voltage also and of course the charging capacitance of the condenser as well as the resistance of the charging circuit.

So, that phenomena can be, that expression can be done but in this case normally we assume that tau we represent as the RC=C the time required by the condenser to attend 0.63 times of its charging voltage. So, now if we look into that t/Rc*C=1, so in these cases, the time constant is considered equal to Rc*C. So, in that case, Vct=V0*1-e to the power -1. So, if we estimate it will be V0*1-e to the power - and if we calculate approximately 0.638.

So, that calculation comes here, so in these cases that significance of that tau can be represent, tau equal to is a constant, Rc*C so Rc is the charging circuit resistance, C is the capacitance of a condenser. So, we can make as a constant but this constant is there, it represents with interpretation of that time required by the condenser up to 63 times of its charging voltage.

So, when it is reached to the 63.8% of its charging voltage that is that amount that time constant is called as the, that is called the time constant for this discharging circuit in this case, fine. In this case from equation 1 and 2, once we establish this equation and if we go back to equation 1 here this equation. So, it is a function of V0, Vct and Rc if we put the value of the Vct here.

We can reach this kind of expression where is the charging current can be in terms of the other parameters, so it is also as a function of time V and other terminology is basically more or less constant, it is a function of time t. So, Rc, C, pressure and t so that we can express the charging voltage and charging current in this RC circuit of the electro discharge machining process.

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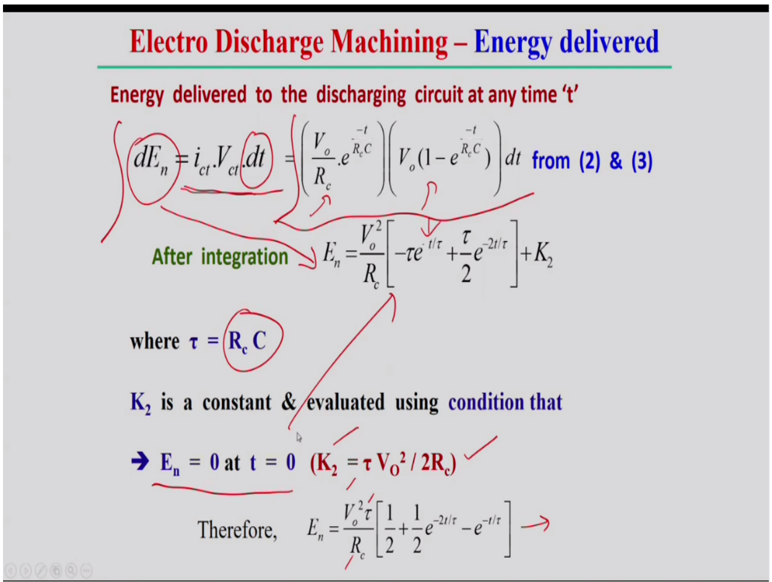

Now, you can look into the further. Now, what is the energy delivered because spark is created was the amount of the energy delivered of the tool to the workpiece. We can estimate this thing, so energy delivered to the discharging circuit at any time t we can estimate what is the amount of the energy delivered, would say what is the elemental energy delivered at the discharging circuit.

We can see that we have already estimated what is the charging current and charging voltage in this case and that voltage into current represents the power and power when you multiply by the time component, then it represent the energy. So, basically the elemental energy delivered at a particular time in this we can estimate the voltage current and the elemental time in this case.

Now, if we put the IC value here current and voltage in these cases from equation 2 and 3 and if you do integrate, do the integration, so total energy supplied to the discharging circuit that can be estimated by simply integration from that. So, if we look into the integration means if we do the integration here, do the integration here, then we can reach the En equal to, after doing the integration we can reach this expression.

And then K2 is simply a constant of this integration but of course here the tau we represent the tau is basically the time constant that is equal to the Rc*C this time constant and then K2 is a constant and of course this K2 has to be evaluated some kind of the initial conditions from this equation. So, at the initial at time t=0, we assume that En=0, so once we assume this put this initial condition this equation.

Then, we can estimate K2=tau*V0 square/twice Rc. If we put we can reach this kind of expression. So, from here we can estimate that what is the energy delivered in this case and if we put all these values, we are getting this kind of the expression here C is a function of time, V0 square Rc and this also has a time constant here, we can introduce the time constant here and we can reach this kind of expression.

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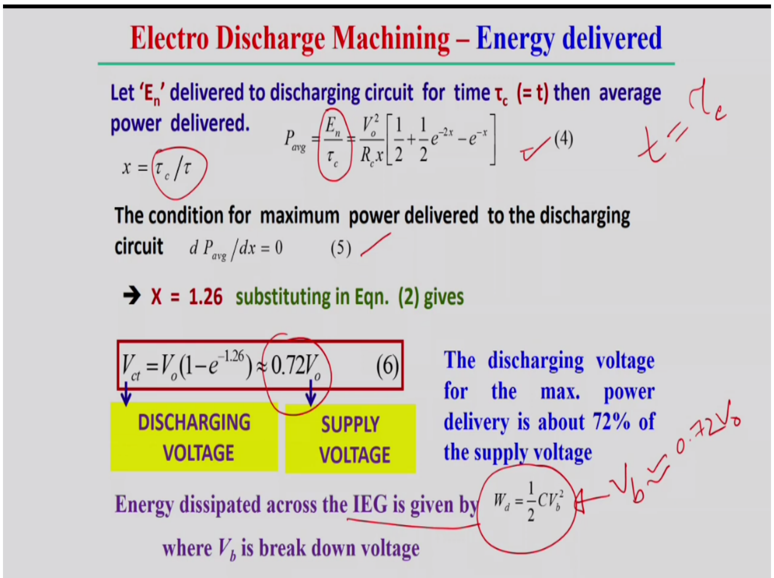

Now, let energy delivered to the discharging circuit for time tc, then average power delivered can also be estimated like that. So, suppose the En is the energy delivered to the discharging circuit but that En is the energy delivered to the discharging circuit for the time constant. So, here for example for the time so limit t correspond to the tau or we can say the time constant as a particular for a time tau c up to that time.

When the average power delivered, X can be represented that En/tau c is basically V0 square/X. If we see here, the total energy supplied sorry total energy supplied here as this is the estimation for this thing. Now, if we do at a particular time, delivered up to that time tau c, up to that time tau c what is the average power delivered, average power delivered can be represented that En/tau c, tau c means up to that time.

So, now tau c can be represented that tau c/tau is basically, so tau c is up to some critical time for example, then we put this expression, we can modify the equation 3 and we reach this expression 4 where X=represented tau c/tau, tau is the constant. Now, the condition for the maximum power delivered to the discharging circuit. When you try to reach what are the maximum power delivered to the discharging circuit?

If we do the derivative of these things, we can reach d P average/dx=0. So, if you put that we can find out X is basically 1.26 is coming in these cases my estimates and if we put this value, we can reach the charging, discharging voltage is basically this 1-e to the power -1.26 it is 0.72*V0, V0 is actually the supply voltage. So, charging voltage and the supply voltage if you see the discharging voltage for the maximum or we can charging of the condenser voltage.

We can say the maximum power delivery is about 72% of the supply voltage. So, when the discharging voltage at maximum power delivered is equal to the 72% of the initial voltage or may be supply voltage. So, that is a X that we can say from this expression and of course energy dissipated between the inter electrode gap can also be represented by 1/2 CVb square, Vb is the breakdown voltage, so that breakdown voltage is possible to estimate.

So, breakdown voltage is basically here, you can see Vb can be estimated that Vb approximately can estimated 0.72*V0. So, then we can estimate that energy dissipated along within at the inter electrode gap can be estimated from this expression Wd=1/2*CVb square.

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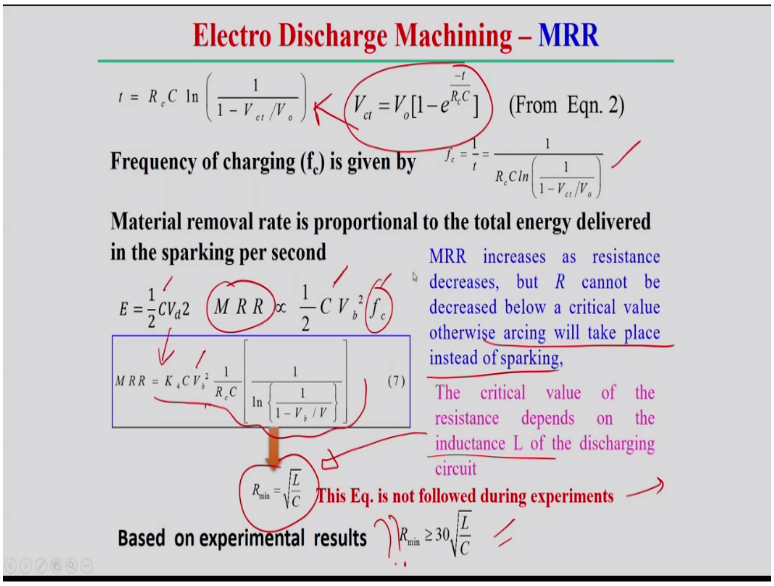

Now, material removal rate, how we can estimate the material removal rate in electro discharge machining process? We can see the t is the time from we have already from this equation, so from here we can estimate what is the time component here and frequency of the charging can also be given fc=1/t, we can estimate this. Then, material removal rate is proportional to the energy delivered in the sparking.

We know the material removal rate is actually proportional to the energy delivered in the sparking per second. So, we can say 1/2 CVb square and fc, e also can be represented the 1/2 CVd square that we have already estimated these things. So, from here we can estimate the material removal rate, remove the K is the constant of proportionality and here you can see 1/2 sorry CVb square is proportional to this part and we can see from here is the remaining part is the frequency.

And then it comes to that expression it depends on this. So, material removal rate increases as resistance decreases, that is observed material removal rate actually increases if resistance decreases but R cannot be decreased below critical value. So, some critical values should be required, otherwise arcing will happen, so instead of the sparking. So, we need to estimate the critical value of the R.

But critical value of the resistance can be estimated the root over L/C, L is actually the inductance L of the discharging inductance, L is the inductance of the discharging circuit. So, that critical value of the resistance it depends on the inductance of the discharging circuit as well as the capacitance but practically this is not following the experimental expression. So, based on the experiments R should be greater than 30 times of the root over of L/C.

So, that is the expression for the minimum resistance. So if you know all these parameters values and then you can estimate what is the material removal rate in case of the electro discharge machining process.

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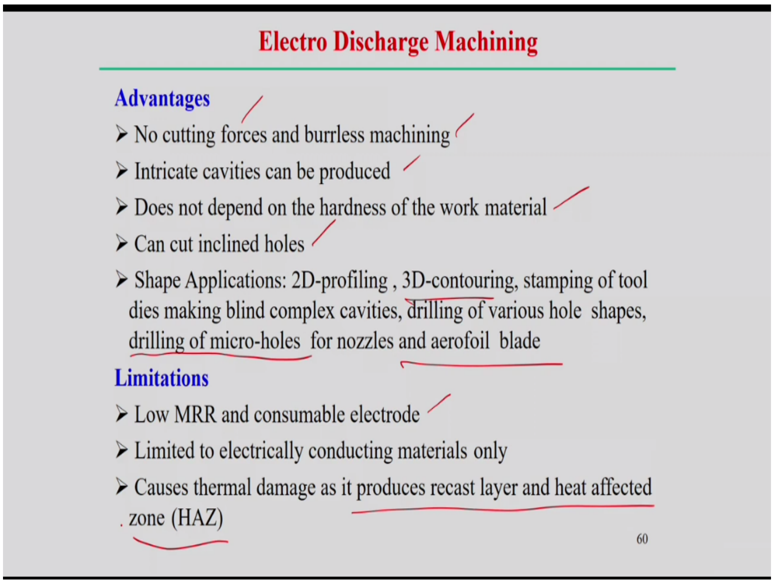

If you look overall what are the advantages and disadvantages of electro discharge machining process we can see no cutting forces and burrless, no cutting forces happens burrless machining process. Intricate cavities can be produced by this process, does not depend on the hardness of the workpiece material that is well known, can cut inclined holes also possible, depend shape application.

We can see that 3D-contouring, stamping, drilling of the different types of the hole shapes. Even drilling up the micro-holes for nozzles and aerofoil blades we can apply the electro discharge machining very precisely in these cases but in these cases limitation is the material removal rate and consumable electrode, is very much limited to the electrically conducting materials and of course causes the thermal damage, it produces the recast layer and the heat affected zone. That is the main limitation of the electro discharge machining process.

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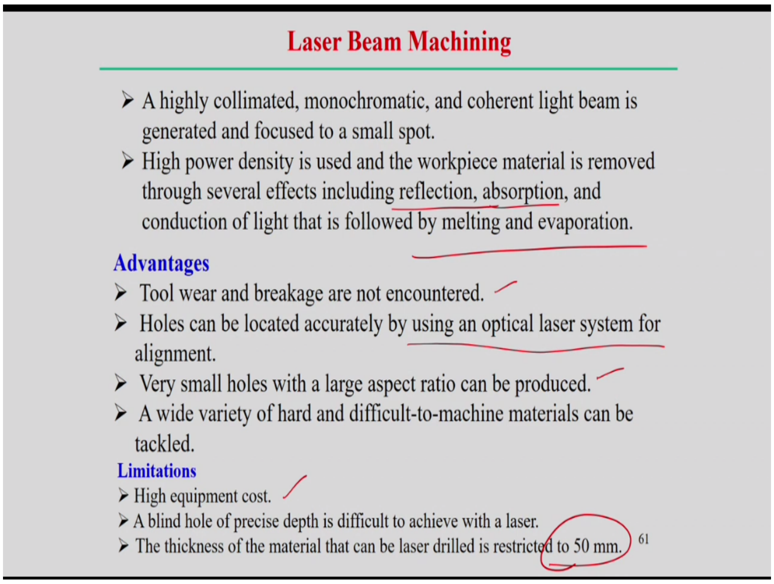

Say apart from this electro discharge machining process we can overall look into the laser beam machining process. So, laser beam principle is well known fact but in this case in laser beam that can also be used to several purposes laser. Well, laser beam machining also possible in this case, normally we use the very high power density laser to remove the material in this case.

And we can see the workpiece material is removed with the several effects reflection, what is the amount of the absorption of the laser and conduction of the light that is followed by the melting and evaporation. Actually, in most of the cases we can use the laser beam machining process, we can use the pulse laser and that whether it is melting or evaporation happens, it depends on the pulse energy supplied with a particular time instant so what the duration of the pulse on time.

Advantages; tool wear and breakage are not encountered, so basically non-contact process laser machining process, so there is no question of the tool and breakage of the encounter. Holes very precisely can be created accurately and other processes work by simply controlling the optical system alignment, position and all depends on the laser parameters we are using. Small hole with large aspect ratio can be produced in these cases.

And basically very hard material difficult-to-machine materials can be tackled using the laser beam machining processes but main limitation is the high equipment cost, very blind hole of precision, precise depth is very difficult to achieve within using a laser, so of course very accurately depth of penetration can be limited, maximum it can reach to the 50 millimeter.

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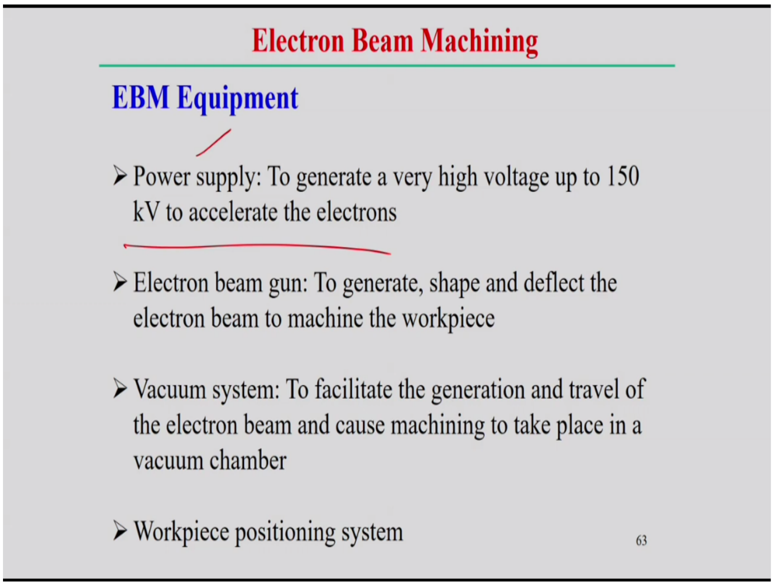

Now, electron beam machining process; similarly, we use the electron beam in this case instead of laser here and focused beam high velocity electrons actually impact on the surface can be drilling and machining, cutting operation can be performed using this process. So, very high velocity electrons basically strikes the workpiece, release the kinetic energy and converted to the heat necessary.

Rapid melting and vaporization is happens at any material but it depends on the what is the material kinetic energy can be released during this process and of course it depends mass and the velocity of the electrons. In this case, up to velocity can be reached 30 to 70 percent of the speed of the light; we know speed of the light is 3*10 to the power 8 meter per seconds. So, in this case that highly precision material removal is possible using the electron beam machining process.

And of course as compared to the laser beam machining process, so equipment, see simply power supply is required to generate the high voltage up to 150 kilovolt to accelerate the electrons. Then, electron beam gun to generate shape, deflect the electron to a particular directions where supposed to do the machining process and of course all this machining process normally prefers under the vacuum.

So, it facilitates the generation and travel of the electron beam and causes the machining to take place in a vacuum chamber and of course one very precision positioning system of the workpiece is required in this process.

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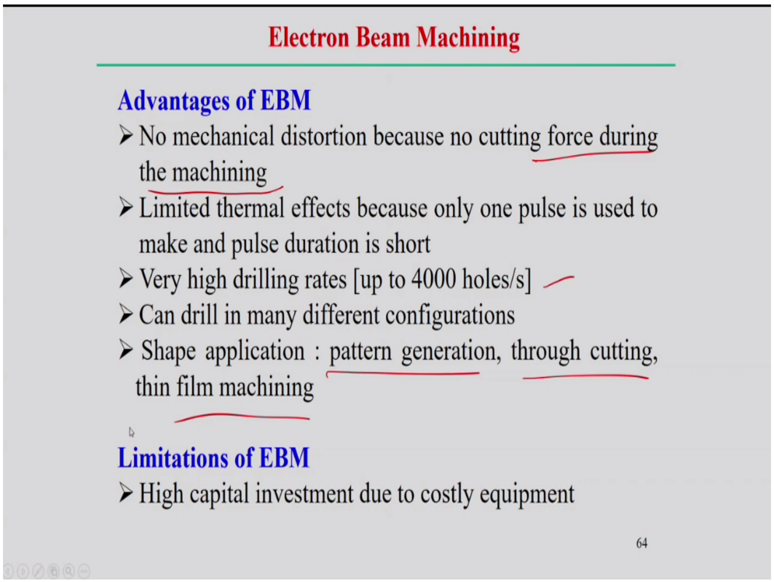

Advantages; mechanical distortion minimum, no cutting forces during this because it is also non-contact process, limited thermal effects and because in these cases not much time to thermal energy dissipated to the surfaces to the material. So, thermal the distortion is minimum in these cases, high velocity during, rate is very high in these cases, drilling different configuration more precisely.

It can be used more depth as compared to the laser beam machining process, can also be applied pattern generation through cutting, thin film machining process can be used in these cases but main limitation of this process is that high investment, high cost of the equipment.

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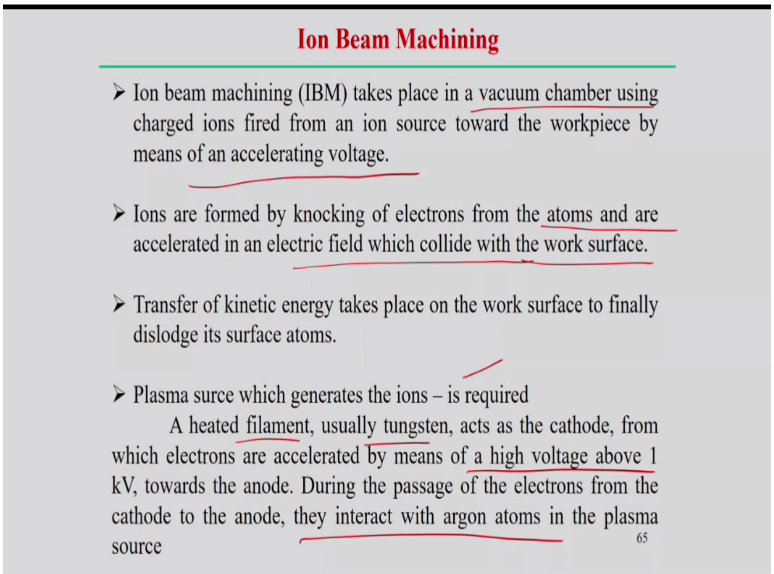

Similarly, ion beam machining process is simply takes place in the vacuum chamber but using the charged ions in these cases and of course we need a source of the ions and that ion source is deflected towards the workpiece where we need to remove the material and it should be accelerating, it should be accelerated in these cases. So, ions are formed by knocking the electrons from the atoms and are accelerated in the electric field which collides with the workpiece surfaces.

But in these cases, transfer of the kinetic energy takes place on the workpiece surface and finally dislodges the surface atoms but some plasma generation is required in these cases. Normally, what we can generate the plasma, heated filament used normally tungsten, acts as the cathode and from which electrons are accelerated, emitted electrons are accelerated with the high voltage and above 1 kilovolt.

And that is accelerated towards the electrode and during the passage of the electrons from the cathode to the anode, sometimes they interact with the argon gas in the plasma source and that plasma that ion creates and then ion actually impact on the workpiece and it works in this process. So, thank you very much for your kind attention.