Manufacturing Processes II
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Lecture No.38
Electrochemical Machining

Good Morning! Welcome to the class on Manufacturing Processes – II. Today we are going to discuss on electrochemical machining. I am Doctor Soumitra Paul. This belongs to the module number 9 on non-traditional manufacturing processes. This is lecture number 9.5. Before starting the actual lecture, let us go into the instructional objectives. Instructional objectives as you know by now, are the points or topics that you are going to learn once you go through this lecture. In today's instructional objective,

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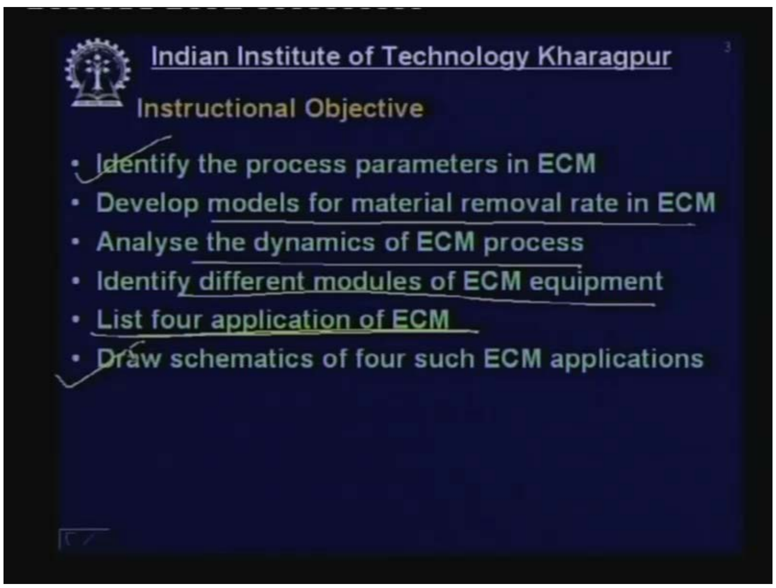

once you go through the lecture, you would be able to identify the electrochemical machining which is in short known an ECM as a particular type of nontraditional processes. Already we have covered a few nontraditional processes, you know abrasive get machining belongs to mechanical group of nontraditional processes. Similarly ECM you would be able to associate with a particular type of nontraditional process. Once we have done that, you would also be able to describe the basic working principle of electrochemical machining. You would be able to draw the basics of ECM, so that you can describe the working principle along with figures.

In electrochemical machining, electrodes are used for machining. So across the electrode there will be potential drop. So you would also be able to understand and schematically draw the tool potential drop. In any nontraditional machining process, material removal rate is one of the major machining characteristics. It is to be enhanced without sacrificing the product quality.

So in today's lecture, you would also be able to describe material removal mechanism in ECM. Later on, you would be able to identify the process parameters and most importantly develop material removal models in electrochemical machining. Now electrochemical machining is a dynamic machining process. So analyzing the dynamics of electrochemical machining process is also very important. There are different modules in electrochemical equipment. So they are to be identified like any other machining process there are specific application areas for ECM which would be listed and we would also give you schematics of those application areas. So this briefly describes the instructional objective. Now let us go into the classification of nontraditional machining processes.

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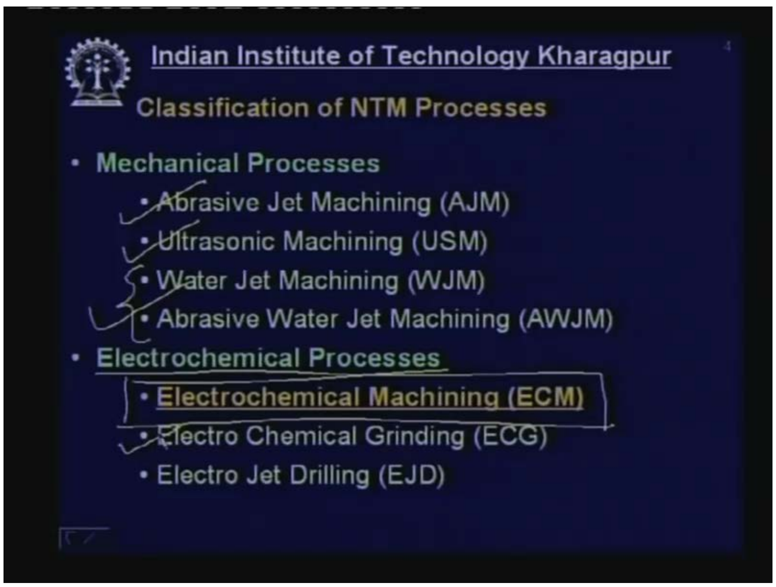

This is your fifth lecture on nontraditional machining process module. So, already you have gone through quite few of them and in the process, you have learnt that there are mechanical processes, there are electrochemical processes and there are electrothermal processes and chemical processes. Before today's lecture, we have already covered electro discharge machining in the previous lecture. We have covered abrasive jet machining, ultrasonic machining, water and abrasive jet machining which were belonging to mechanical process and today our aim is to understand the basics of electrochemical machining which belong to electrochemical process segment. Within that process segment, there are two more processes. One is electrochemical grinding, another one is electro jet drilling. However today we will concentrate on ECM or electrochemical machining processes.

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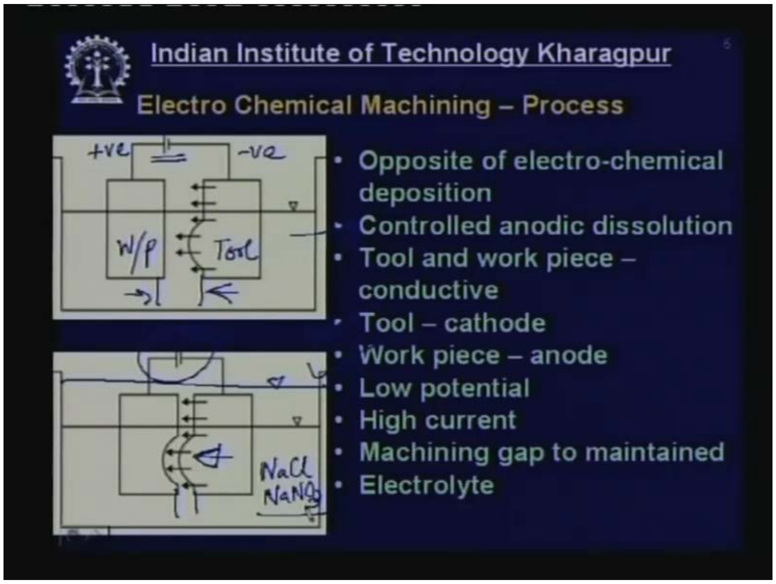

Now let us come into the electrochemical machining process. In electrochemical machining process, like any other process we require a workpiece as well as we require a tool. So, this is my tool and this is my work piece. They are emerged in a solution just like electro discharge machining but this solution is not dielectric like electro discharge machining. This solution is that of an electrolyte. Typically, sodium chloride salt is used to prepare an accurate solution and the electrolyte. What is electrochemical machining? Briefly, it is just the opposite of electrochemical deposition. This is controlled anodic arc canodic dissolutions. So this is my work piece. So this was my workpiece and this is an anodic dissolution. So this is controlled anodic dissolutions.

So, if you look here the workpiece is connected the positive terminal and the tool is connected to the negative terminal. What is the next point? We have already covered tool is my cathode and work piece is my anode. There are other characteristics of ECM process as well, typically the voltage which you apply is a low voltage slow potential but the amount of current which passes through this particular electrochemical shell is rather high. Now, there is a machining gap. Initially the machining gap could be rather high but during steady state operation the tool has to be feed continuously, so that a specific gap can be maintained and as we have already said, the whole thing has to be emerged in an electrolyte solution and sodium chloride or sodium nitrite. These aqueous solutions are the typical electrolyte solutions which are used in electrochemical machining process.

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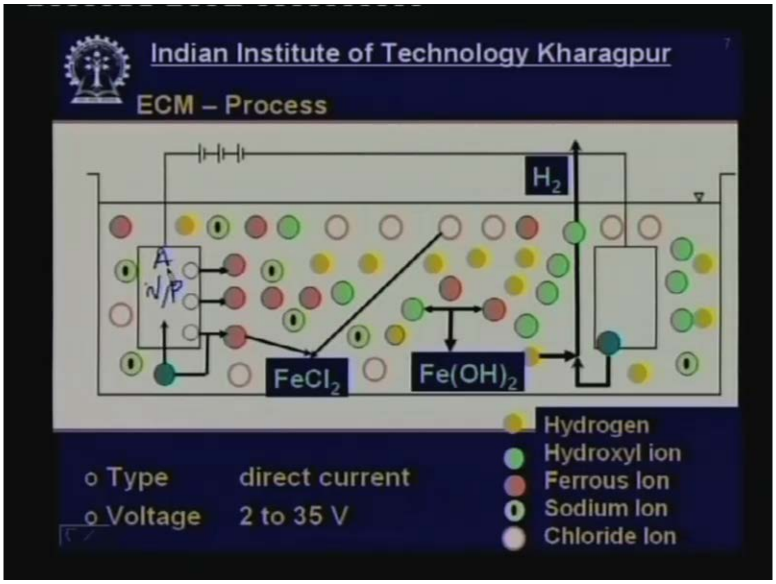

Now let us schematically see what happens? Typically when someone is trying to machine a ferrous material, different types of materials can be machined. But for today's example; schematically we want to show what happens when it is a ferrous material. So let us come to the graphics. So this is describing the electrochemical process and this is my workpiece and this is my tool and once we apply a potential difference, then what happens because of electrochemical dissolution. This is my electrolyte, this is my electrolyte and the electrolyte could be sodium chloride electrolyte. So what happens? As because it is aqueous solution in this particular electrolyte, you would have chlorine atom so these are your chlorine ions.

Similarly you would have sodium ions. You would also have hydroxyl ions because water will dissociate and once the shell is switched on, once current is passing through it. As because work piece is made up ferrous ions, ferrous ions will react with chlorine ions as being indicated here to form ferrous chloride and they can also react with hydroxyl ion to form ferrous hydroxide. What happens to the hydrogen ions? These are the hydrogen ions hydrogen ions would be positive. So they will go towards the tool material which is connected to the negative terminal and hydrogen gas will evolve. So, in summary what happens in electrochemical machining process? I have a work piece, I have a tool.

I apply a particular potential difference. The tool is connected to the negative terminal and the workpiece is connected to the positive terminal and the whole go as well as workpiece and the tool they are emerged in an electrolytic solution. Typically, sodium chloride or sodium nitride solutions are used as the electrolytic solution. I apply a DC current and the typical voltage applied is 2 to 35. As because it is sodium chloride solution the aqueous solution, I would have sodium ions and also have chloride ions and once the shell is switched on, iron will it come out of the workpiece and react to form sodium chloride or sodium hydroxide and hydrogen will evolve from the cathode. In this way due to controlled anodic dissolution, we will get machining on the anode or work piece. Now you have already seen, this is my work piece which is anode and this is my tool which is cathode and I am applying a potential difference between them. Let us try to study how that potential difference drops in a particular ECM shell:

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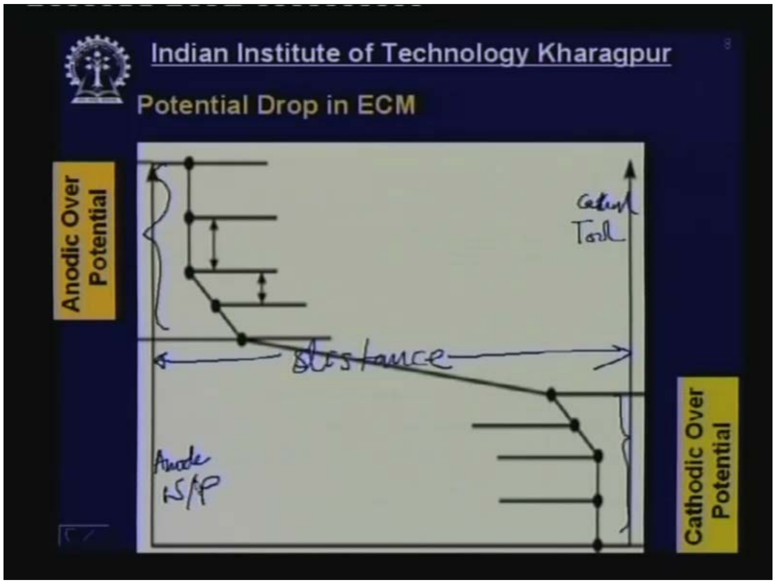

What we have here? This side is my anode and this side is my cathode. So the total potential drop over here is the anodic potential drop and the total potential drop here is called the cathodic potential drop. What is this separation? This is the separation or distance. This is the distance between my two electrodes. This is cathode. So this has to be my tool this is anode. So this has to be my workpiece and this is the distance of separation.

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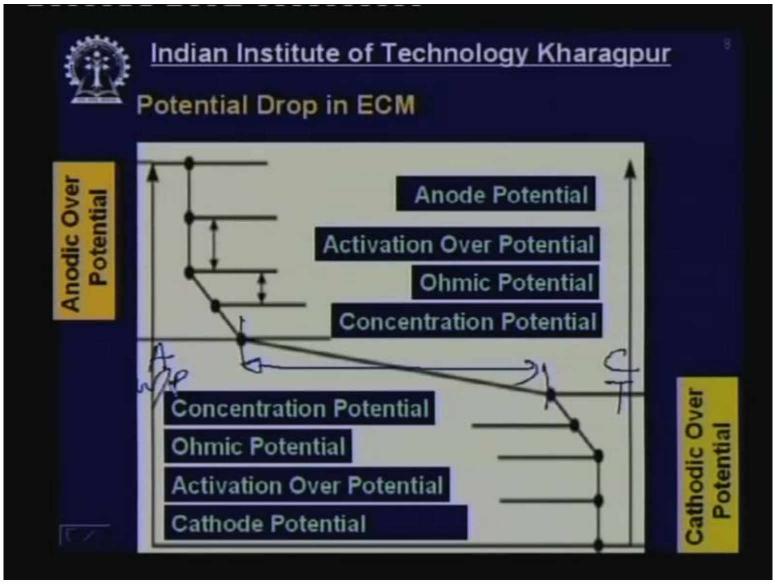

Now first drop is the anodic potential drop at the anode and similarly the cathodic potential or cathode potential drop at the surface of the cathode which is followed by activation over potential. You require a bit of over potential to establish the flow of electrons and ions to the shell. So this is the activation over potential. Then, you have ohmic potential drop within the cathode and anode and similarly you have the concentration potential drop because once electrochemical machining or deposition starts, there would be some concentration gradient near the electrodes and then from this point to this point, you have the electrolytic drop through over the almost complete separation distance between my cathode and anode or in other words tool and work piece. So in this way the potential drop occurs in electrochemical machining. To have electrochemical machining, I have to provide a potential. So that all these potential drops can be achieved and gone beyond. So that there is an electrolytic drop which drives the shell or machining process.

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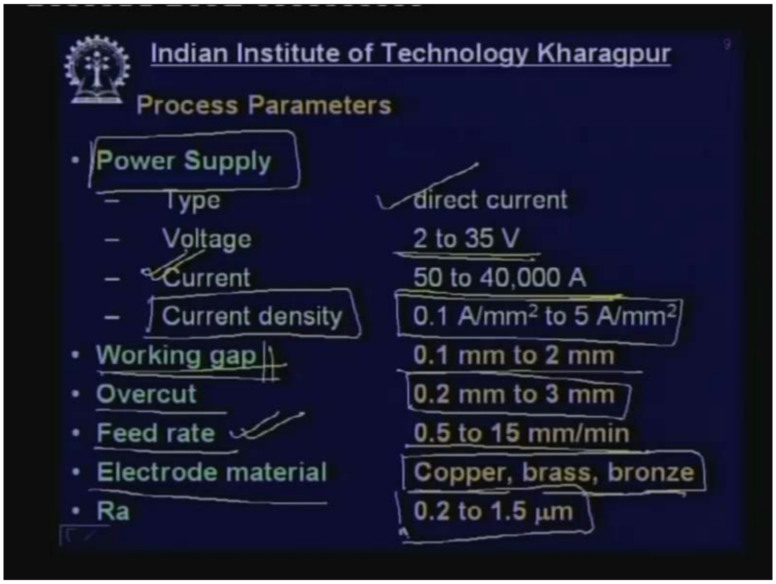

Now let us come to the process parameters. As you know, if you cannot identify the process parameters, understanding the basic process becomes difficult. Without knowing about the process parameter, you cannot optimize, you do not know what is the effect of a particular process parameter, on one of the most important machining characteristic that is material removal rate or product quality. So we need to understand what are the process parameters fast, for any machining process and today we are going to do that for electrochemical machining. As we said, one of the major area or major item in electrochemical machining is the power supply that means what kind of power we are going to give generally DC power would be given.

We have already identified, it is a low potential. The voltage applied is rather low around two to thirty five volt. However, the current capacity of your power supply has to be very very high, around fifty to forty thousand ampere. More so, the process is identified not by the current but by the current density. Current requirement is very much important for the machine manufactures, but current density this particular term is very very important as per identifying the process is concerned and the current density as you can see is around 0.1 ampere per millimeter square to 5 ampere per millimeter square. So current density is nothing but the current divided by the area of the electrodes.

Now, we have already understood that there has to be working gap between the electrode and the workpiece and that working gap is around 0.1 millimeter to 2 millimeter. Just like electro discharge machining as we have discussed in ECM as well there is some amount of overcut when we go into the schematic of the actual drawing we will once again show you how to control that overcut. As we said to maintain a particular working ah gap the tool has to be feed and it has to be feed with a particular feed rate which varies in terms of 0.5 to 15 millimeter per minute.

You can see the the feed rate is rather high 15 millimeter per minute. So the material removal rate in electrochemical machining would also be high. Electrode material can be copper brass and bronze. It can machine any material which is electrically conductive irrespective of their mechanical properties and the tool materials are typically the copper brass or bronze. Surface softness obtained are very good. It is as less as 0.2 to 1.5 micron but quite often it is rather less.

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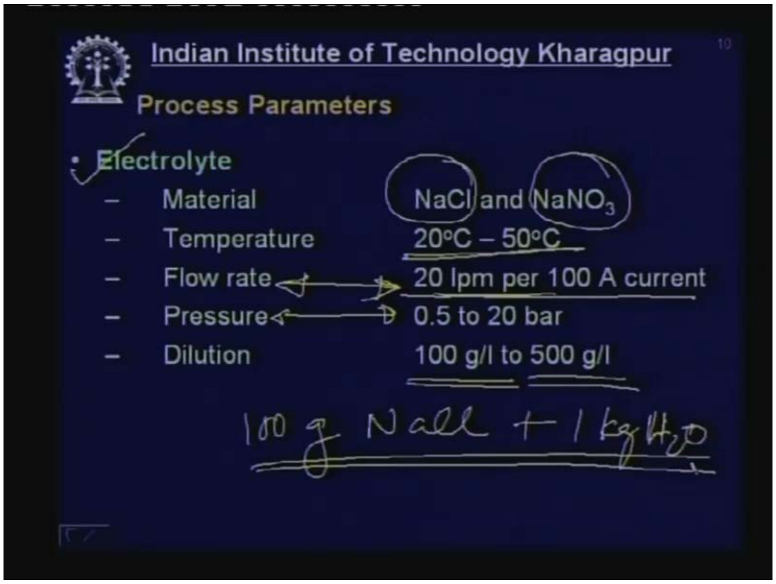

Once again we have the electrolytes. So electrolyte also plays a significant role in electrochemical machining. Typically either aqueous solution of sodium chloride or sodium nitrite is used. A temperature is required to be maintained and a flow rate has to be maintained because during the machining process, sodium if you are machining iron based alloys, iron chloride or iron hydroxide are forming during the machining process those are sledges. If they are not removed continuously your molar concentration of the electrolyte is going to change.

Thus you need to have a substantial flow rate so that those sludges can be removed continuously and for that you also require a pressure. Typically the dilution is around hundred grams to five hundred grams per liter of water. So, hundred grams of sodium chloride is formed with one kg of water or one liter of water to get a particular electrolyte in for electrochemical machining. Now let us come to the characteristics of electrochemical machining. In characteristics of electrochemical machining, we will be talking about what are the typical properties required of tool material and work material.

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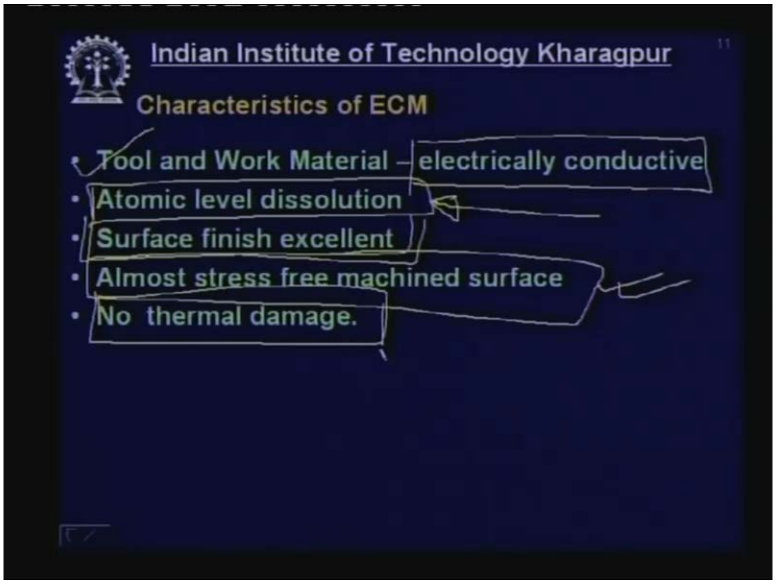

Tool and work material both of them are to be electrically conductive. So it is very similar to your electro discharge machining. Just as in electro discharging machining, your tool and work materials are to be electrically conductive. Similarly in electrochemical machining, they are to be conductive. If you remember as far as abrasive jet machining, water jet machining, abrasive water jet machining and ultrasonic machining was concerned. There the domain of the energy was mechanical in nature and thus you do not require the material the work material to be electrically conductive. Here as well as in electro discharge machining, they are to be electrically conductive.

What are the next characteristics? The material removal characteristics: Material removal occurs by atomic level dissolution. As we said, electrochemical machining is the just the opposite of deposition electrochemical coating on deposition process. So it occurs due to atomic level dissolution and as because it is atomic level dissolution, the next point is very very simple to understand: You need you get a very very excellence of its finish. Thus as because it is atomic level surface finish is expected would be very good and here you can get a surface finish as low as zero point one to zero point two micron Ra value which is very very good. Now let us come to another point:

In any kind of mechanical grinding on machining process or even in electro discharge machining process where there is lot of thermal effect you would be getting lot of temperature damage. So there could be residual stress but in electrochemical machining almost stress free machined surface are obtained. There is absolutely no residual stress so in strategic sectors where the material machine machine component should not have any residual stress this is a very good solution electrochemical machining and as well as there is no thermal damage a rather as because there is no thermal damage and as because the dissolution is atomic level will get residual stress free machine surface. Now let us come to the modeling of material removal rate.

Till now, we have discussed around four different electrode non-traditional machining processes and in all those non traditional machining processes, we have tried to model material removal rate because material removal rate determines how fast you can make machine. So how much would be your machining time? So that in turn will determine what is your productivity even what would be your profit rate and all those functions. So it is a very important phenomenon to understand. So that later on it is as because it is later on related to even techno economical viability of that particular process. So, now let us come to the modeling of material rate in electrochemical machining.

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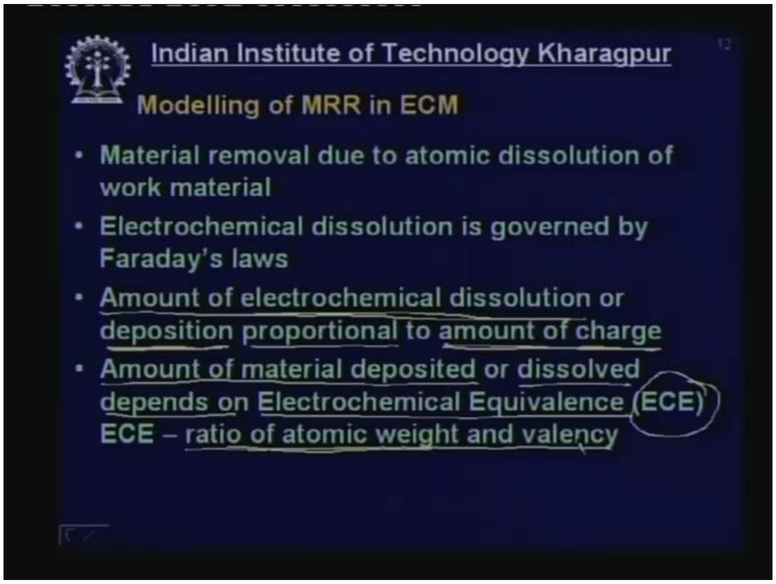

We have already understood, material removal occurs due to atomic dissolution and as we know electrochemical dissolution is governed by Faraday's laws of dissolution. So this is a very simple law and which can be used to model electrochemical machining process. What the law says? It says amount of electrochemical dissolution or deposition. This law is not only for dissolution it is equally applicable for coating process or deposition process. So amount of electrochemical dissolution or deposition is proportional to proportional to what? Amount of charge that we pass through the electrochemical shell. This is the first statement of the law. What is the second statement of the law? Once again, amount of material deposited or dissolved incase of machining it would be dissolved.

The amount depends on or proportional to something which is called electrochemical equivalence which is typically denoted in the industry by ECE and what is this ECE? ECE is related to the ratio of it is the ratio of atomic weight and valency of dissolution. So we have two laws and we need to use these two laws. So that we can come up with an expression for material removal rate. Material removal rate is a very very technical characteristics and we want to use these two basic laws to try to come up with expression for material removal rate.

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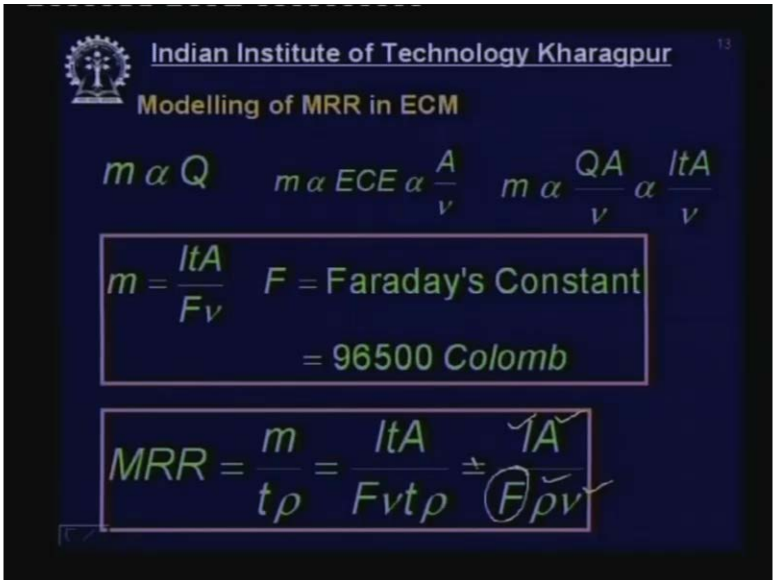

So what was the first statement? The first statement was amount of material dissolved or deposited is proportional to charge. So this is the statement given in the mathematical form. Mass is proportional to charge. What was the second statement? Second statement say the amount of material is proportional to electrochemical equivalent and which is the ratio of atomic weight by valency. So now I can combine this expression as well as this expression these two. So to say expression mathematical expression to get third one which says combining this mass is proportional to charge, as well as atomic weight divided by valency. So its very nice expression and once again charge is nothing but current. How much current I am passing for what duration? So i t into atomic weight divided by valency.

This can be expressed in a equation from not proportionality form like amount of material dissolve or machine or deposited is equal to i amount of current pass into time, into atomic weight divided by valency and now I have a constant which is the Faraday's constant and Faraday's constant the value is 96500 colomb. So this is my constant. So I can say, if the total amount of charge passed is 96500 colomb, then amount of material removal would be exactly equal to the atomic weight divided by the valency. So if the atomic weight is ten, valency is two your mass dissolution would be five grams.

Now, this is the amount of mass dissolved. Now we want to get material removal rate. Material removal rate, if you remember is typically expressed in volume millimeter cube per second or millimeter cube per minute. So, amount of material dissolve divided by time that gives kg per second divided by density will give you material removal rate. So the earlier expression was ITFV into A that stage which divided by t by rho. So, you get this particular expression. So, material removal rate ultimately proportional to current. It is proportional to atomic. It is inversely proportional to the valency. It is inversely proportional to density and there is a constant which is Faraday's constant.

However this particular modeling that we have done is for elemental material that means if you are machining only nickel using electrochemical de machining or only iron using electrochemical machining but as you know in engineering application, generally elemental materials or metals are not used. Typically alloys are used and what are alloys? Alloys are typically the solid solutions of different elements say for example; steel is an alloy Inconel seven one eight is an alloy titanium six al four V is an alloy. So all these are alloys were there are different types of materials. So let us try to develop the mrr model for a typical alloy or any for that matter. So, modeling of material removal rate for engineering alloys where you expect more than one element.

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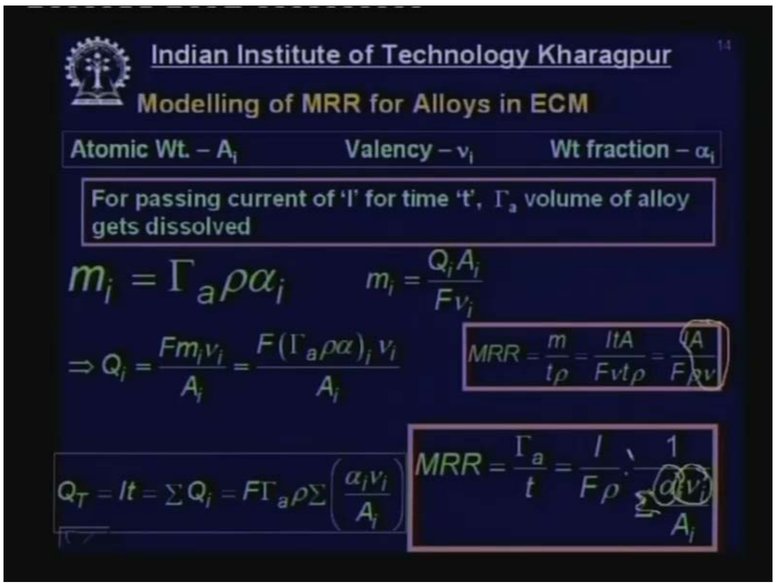

So I have denoted atomic weight by Ai valency by Vi and weight fraction by alpha I. Meaning thereby, there could be I could vary form one to n or one to three. There are three different elements. Now, for passing current of I, with a duration of t there would be a total volume removal which is gamma a. Now what is that expression for volume removal gamma a in to rho in to alpha I, where which one is the weight fraction would be mi. What I am trying to say is that if you pass a current of I over time span of t. You would remove a total volume of gamma a, out of which mi of for that matter m 1 is the total amount of dissolution of the first elements.

How much is that? m 1 is equal to gamma a times rho times alpha i. Now comes the same thing mi equal to Qi into Ai divided by F into vi. This was the expression that we have obtained earlier as well. So, as if to remove m one amount of material of element one, you require Qi or Q one amount of charge. So Qi can be once again expressed as this and using the expression of expression available here you can get an expression like this. Now what is Qi? Qi is as if the amount of charge require to machine the i-th element. So how much would be my Qt? It is very simple. If I know, how much is my Q 1 Q 2 Q 3 Q 4, I can simply sum up to get the value of Qt.

However Q 2 is also I into t. If I pass one thousand ampere of current for ten seconds, I know how much is the total charge and that is sum of all the charges and I have the expression for one charge. So I can simply sum it over overall the charges to get a material removal rate as gamma a by t because this was the volume removal I took this much of time. So I can simply get the volume material removal rate like this. Now if you compare this material removal rate which is for alloy which is for an alloy and for an element. They are very similar. How they are similar?

Material removal rate for an element is proportional to current you are also to it is proportional to current for an alloy. It is proportional to rho it is inversely proportional to here also it is inversely proportional to rho. So where the difference difference is is in case of elemental this is proportional to ratio of A by nu, but here because it is an alloy. there it goes in the denominator and summed up. Why it is summed up? because you have different weight fraction and different valences and different atomic weight. Otherwise if you look at the structure, they are very very similar. Now we have got the expression of material removal rate but, during machining process the tool is somewhere here.

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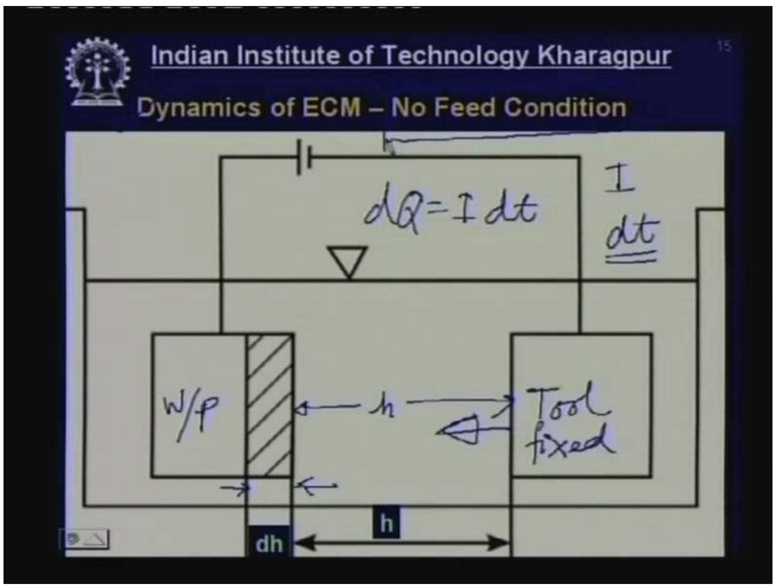

Where is the tool? During machining process, this is my tool and this is my work piece. During a particular instant, there is a distance separating them h and I am passing a current I through the cell over time spend ‘dt’ and when I pass a current of I over ‘dt’ the total charge involved dQ is I into dt and because of that passing of charge, there is further dissolution of this amount. So what happens? Over time, this distance is going to increase. So this is called dynamics of electrochemical machining and as if we are not feeding the tool free tool is fixed here. It is not moving so we want to study what happens to this gap if the tool is not given any feed, no feed condition that’s what we want to study. How would you study?

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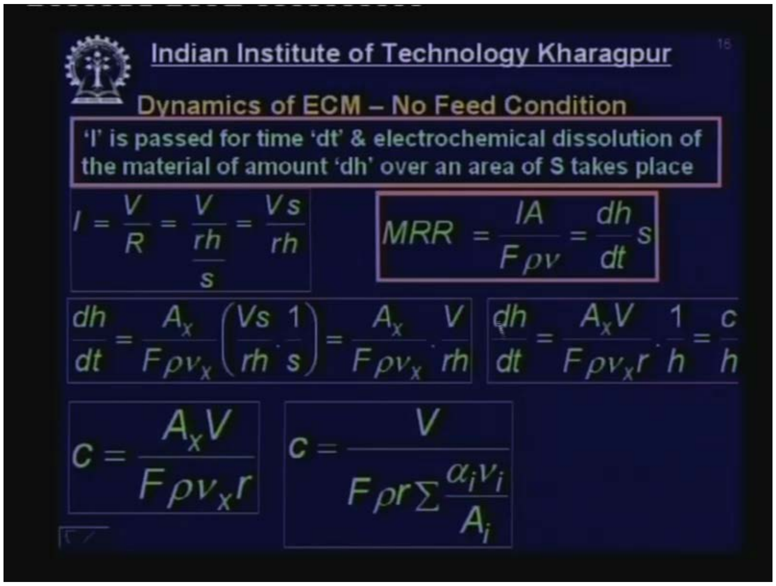

This is the statement I. Amount of current is passed over a time 'dt' and in the process we get a dissolution of dh and over a area of s. What is that area? If you go back to the previous one this is the area s that is the area of the work piece. We already have the expression of I what is that I? I is nothing but the ohmic drop V by R. This is my resistance. So resistance can be written as resistivity into h that is the distance into s. So this is my expression of I in terms of voltage drop, in terms of area of the electrode resistivity and the distance at time t equal to zero. So this is the expression of material removal rate IA by F into rho into v.

This is the standard expression, but material removal rate is also material removal rate is also dh by dt into s dh dt by s because this is the rate at which the material is being consumed or dissolved into the area. So I can write 'dh' by 'dt' in this particular form. What is the difference in this form? Here, you have a suffix of x. x denotes that this is the equivalent automatic weight of an alloy and as well as this is the equivalent valancy nothing more that. So in that way, I can further simplify 'dh' by 'dt' into this and in this particular expression, what you can see is that this part? This part is a constant. So this part is a constant which has been taken out here and we can say this constant is c. So your dh by dt or dh dt becomes c upon h. So dh dt becomes a function of h and it is an inverse function. So this is your c value of c and further for an alloy value of c can be written like this. This was for a particular element and this is for an alloy composition. Now let us come to let us try to integrate let us try to integrate this particular equation to see what happens actually?

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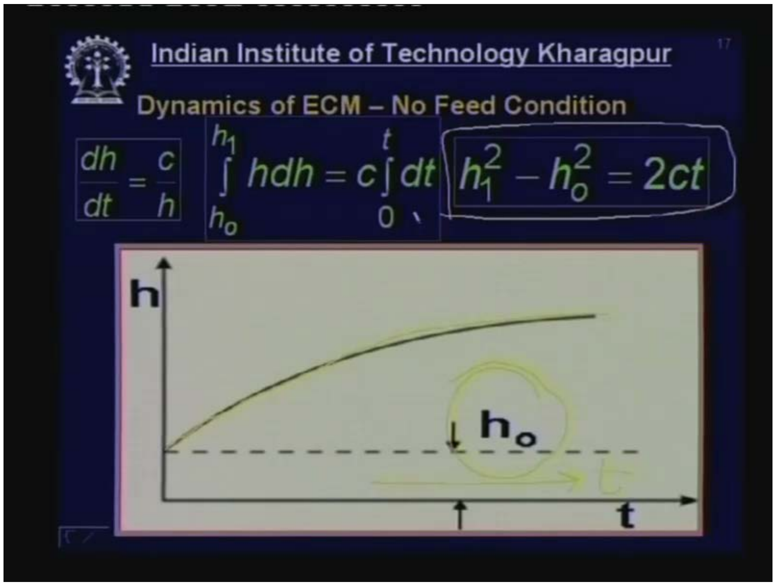

So this is your equation I need to integrate to see how h changes which time. What was h? h was the separation distance. So I you can integrate between initial and some value h one and I get an equation like this. If I plot this equation what happens? This is something like this. What is your h zero. The initial set separation between the tool and the workpiece as time progresses time is your x axis. As time progresses, the h increases in a parabolic manner. Why it increases in a parabolic manner? because that is dictated by this particular equation.

So what happens? As it increases, the distance between the tool and the work piece increases and there is less amount of material removal gradually had the material removal rate being constant this would have been a straight line that is not the case which says this particular expression tells us a this figure tells us that if there is no feed given to the tool gradually the work distance between the workpiece and the tool is going to be increased and the material removal rate is going to fall which is not a good thing. So we have to do something, so that we can maintain the material removal rate. So for that, we need to give feed to the tool and that is what we are going to analyze. Now that is dynamics of electrochemical machining with feed condition.

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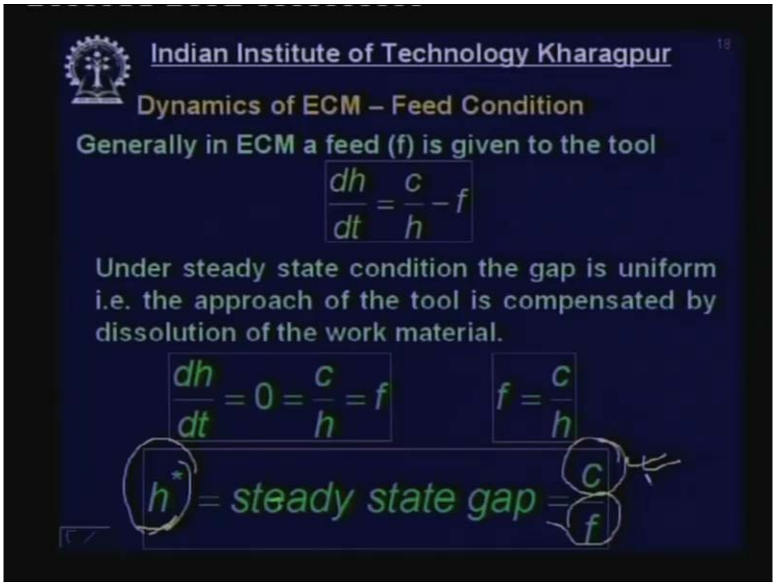

Tool is not longer fixed it is being feed. So, generally it is feed with the feed rate of wave that could be millimeter per second. So, earlier your expression was ‘dh’ upon ‘dt’ c by h is the same expression we are using. But, this was under no feed condition. So, now I am giving a feed so your dissolution would be ‘dh’ by ‘dt’. Now under steady state it is expected but there would not be any change in the distance between the job and the work piece. If there is no change in the distance between job and the work piece, under steady state condition this can be equated to the zero and if it is can be equated to zero c upon h that becomes equal to f or f becomes c upon h.

Now we need to see what happens to that steady state gap h star? So what is h star? h star is the steady state gap. Under steady state condition, it would be dictated by c and f that is c is basically related to how much voltage you apply. How much current is passing through the shell? What is the alloy you are machining? And f is a set parameter on your machine tool. So on that h star will depend. Now this brings or brings us to a very very difficult question.

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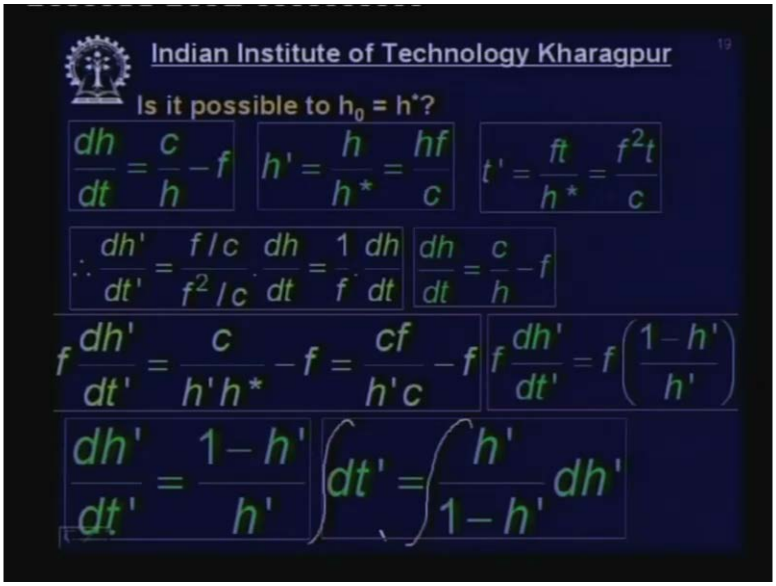

What is that question for a given value of feed and a for a chosen value of current and all other parameters. I get h star of 1.5 millimeter. Now my question is how do I ensure that? Whenever I am starting electrochemical machining, all the time that gap initially that gap is 1.5 millimeter. What happens if I cannot maintain a initial gap of one point five millimeter when my calculated steady state gap is one point five millimeter. This is a very tricky question. You have set all the parameters undergone rigorous courses in electrochemical machining and come up with the steady state value of one point five.

How do you ensure that gap is one point five or what is there any point spending time in setting the initial gap to be 1.5? That is what we are going to check now. First of all, is it possible to set h zero equal to h star. It is possible but it takes time. So should we do it that is what we want to analyze. So once again this is my basic expression dh by dt equal to c upon h minus f where f is the given feed and c upon h the resolution that is under no feed condition. Now we are going to change the variable domain of h as well as t by variable transformation.

So we are basically transferring the domain we are making them non dimensional nothing more than that, so that we can get a non-dimensional expression of ddt prime h prime and that non dimensional expression is also related to ddt of h or that the rate at which the anode is dissolving and now what we need is finally we want to see. How this h prime is going to change and that we will be trying to get by integrating this particular equation between will be integrate in it between t equal to zero to t prime and h equal to h zero prime to h one prime and if we integrated it we get an expression like this and this is the way the curve would change.

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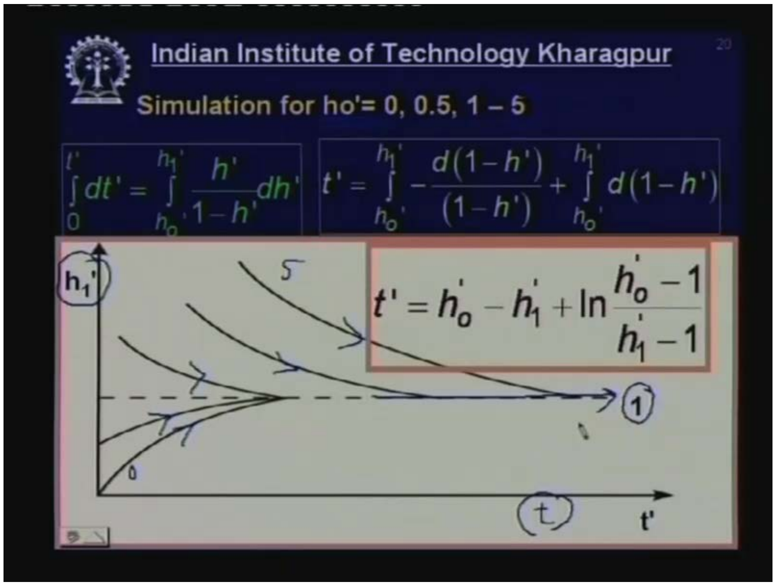

What is there in the curve? It is a very interesting curve. This is my time on non dimensional time and this is my non-dimensional final gap. What is this? This one is the non-dimensional steady state gap which happens to be one irrespective of whatever is your initial value, whether it is zero zero point five or five? This is for zero and this is for five irrespective of your initial gap gradually over time, the same steady state value would be achieved. This is a very good information for us. What was the problem? If you go back to the problem, you would understand. Our problem was getting or setting the machine tool to a particular value of initial gap and we were trying to understand what happens if we cannot set it and what is the result? After analysis, we find that the result is something like this and which is very very in our favor, irrespective of whatever be the initial gap, final value is saturating at one that is the equivalent gap. Thus, we can say irrespective of the initial gap h prime bar or would be one or h would be equal to h star. So it is very very evident.

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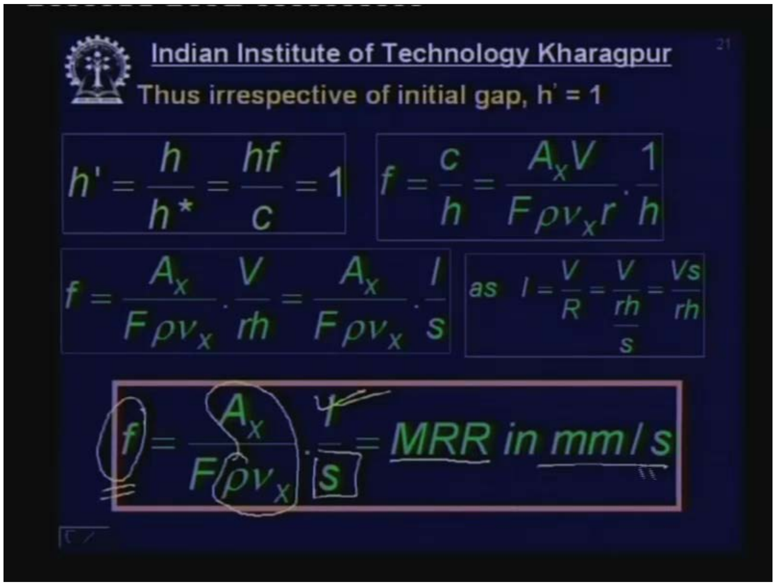

So from that we can get a value of feed rate which has to be set on the parameters. I hope you have got the point. h prime has to be one. So ‘h prime’ was nothing by h upon h star. If you remember h star was c upon f, so this is the transformation. So from this expression we can get a value of f which we have to set on the machine and that depends on what is the voltage you are going to apply, what is the resistivity and what is the alloy composition. f depends on that and as well as it depends on the value of h and ultimately you can get a value of f where this h can be cancelled out.

How it can be cancelled out? We know that I equal to vs by rh, I equal to vs by rh and here I am getting an expression by v upon rh. So I can measure the current and I can set the current on the machine. I know how much is the surface area. This is basically the material, so I know that. So how much would be the feed that has to be set once again. How much would be the feed that has to be set on the machine depends on your current which you are setting it, depends on the area of the electrode which you can measure and it depends on the density valence and the automatic weight of the material, you are machining. So this is also known. So that you can set you can get a particular value of f and this is basically the rate at which materials is removed at the workpiece surface and typically express in millimeter per second. Now let us come to the equipment:

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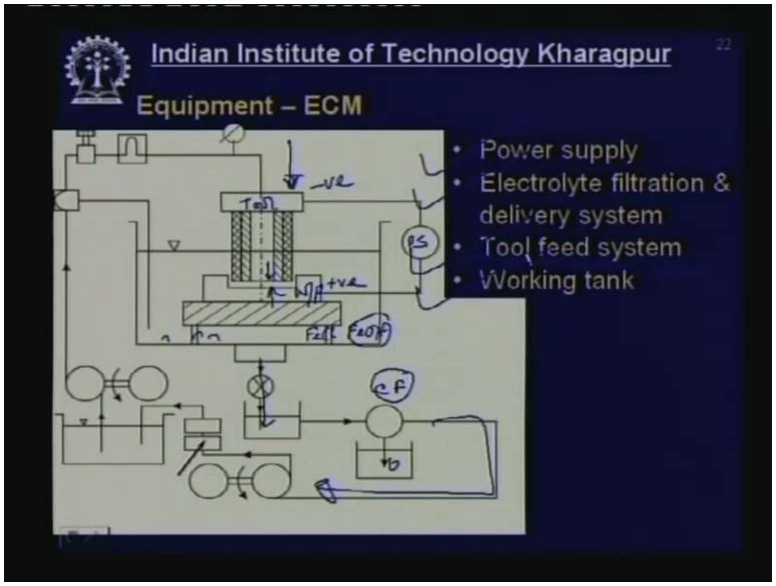

What are the modules that are used in electrochemical machining? Typically we have a power supply we have an electrolyte filtration and delivery system. We have a tool feed system and working tank. Now what are these? This is my electrolyte tank. This one is my electrolytic tank, this one. There I have a motor and I have a pump. So it goes through a pressure reducer as well as a flow meter and a pressure gauge and it enters the tool. Here the tool is a hollow tool and this one is the insulation on the tool. You may ask me why we are going to provide insulation on the outer surface because we do not want an over cut.

So the electrolyte comes like this and moves over the working surface and gradually at this particular place, at this particular places you would have electrolytic dissolution. What is this? This is my power supply. So this is the positive terminal. Sorry sorry sorry. This is your, this is my power supply. This is the tool. So your negative terminal and this is your work piece which is the positive terminal you require a tool feed system because this gap has to be maintained. So you require servo system for feeding the tool.

Once machining has been done sludges would be collected here like so iron chloride or iron hydroxy sodium iron hydroxide. So these sludges are to be removed. So they are taken out by a valve and this is a centrifugal filtering unit or separation units after separation sludges are kept here and the electrolyte is feed back into the system. So this is the basic modules of electro chemical machining and to summarize once again you require a power supply filtration, you need tool feed system and working tank. These are the basics of basic module. Now let us come to the application of electrochemical machining.

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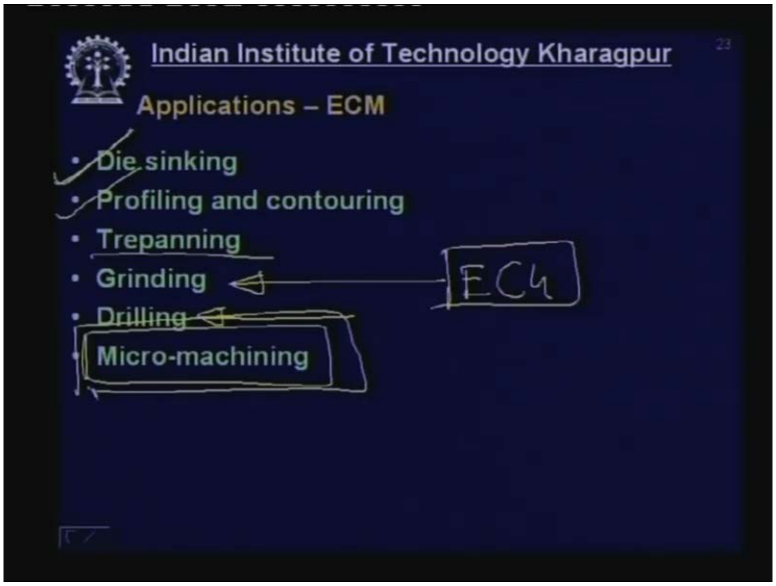

As we have already said, under the characteristics of electrochemical machining. It requires electrically conductive work material. As long as your work materials are electrically conductive irrespective of there mechanical properties like what is there Young's modulus, what is their hardness, it can be machined. What kind of machining operation can be done? Let us come to that. Die sinking can be done in electro discharge electrochemical machining. Very similar to your EDM die sinking, profiling and contouring can be done. This is another very important application area. Trepanning can be done, electrochemical grinding electrochemical grinding this is a technology in its own right. Drilling can be done and another very emerging area of electrochemical machining is micromachining. We are not going to address that, but out of these few applications, now we are going to go into there schematics.

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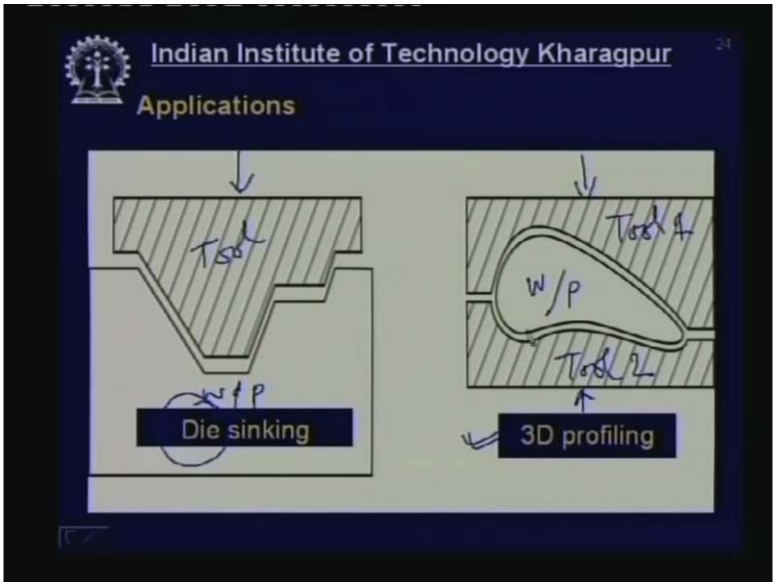

What is die sinking? Die sinking is shown here. This is your tool material and this is your work piece. So gradually the tool is feed in this direction, so that you can get a negative impression of the tool on the work piece. Why is it called die sinking? Because in this manner typically die is which are of very complicated geometry they can be made. This is the 3 D profile say here this is your workpiece and this is the upper part of the tool. So tool one and this is your tool two and this is having a very complicated profile as you can see in the 2 D. It can also have a 3 D profile. So the tool one comes down and tool two gradually goes up to give you a very very complicated complex work piece. Now this is the drilling operation which we have shown earlier as well:

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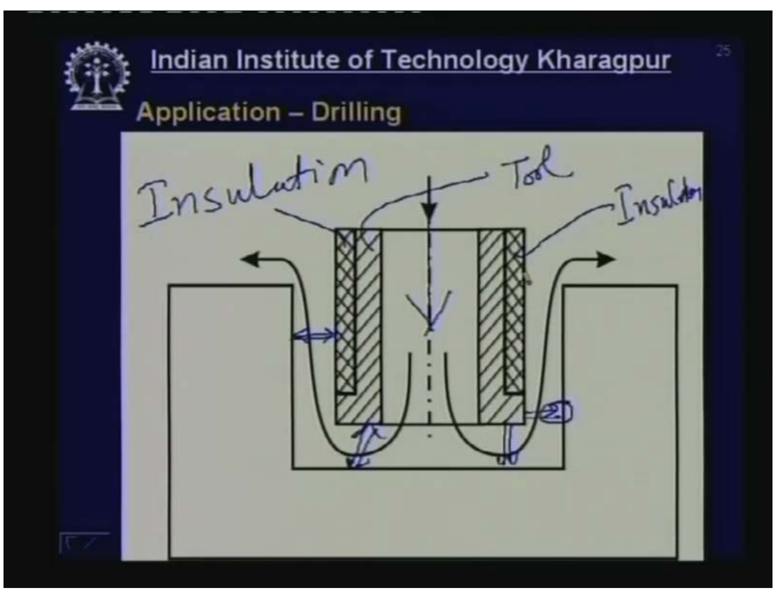

This is your tool and this is a hollow tool. As you can see, there is a hollow hole inside and the electrode is pumped through that hole and it moves like this and on the on the tool, there is also insulation. So that, we have already said, there is insulation on both the sides. Why there is insulation? Already we have mentioned that, there is a problem of over cut once you give insulation. There would not be any electrochemical action here, we want the electrochemical action to be restricted just below the tool surface. However, you can restrict it here. So there is some machining or overcut at least by insulation the overcut can be reduced to some extend and this way you can a drill a whole depend and it the hole can be large hole as well as small hole or it can as well be of complex shape. Now let us come to the trepanning operation.

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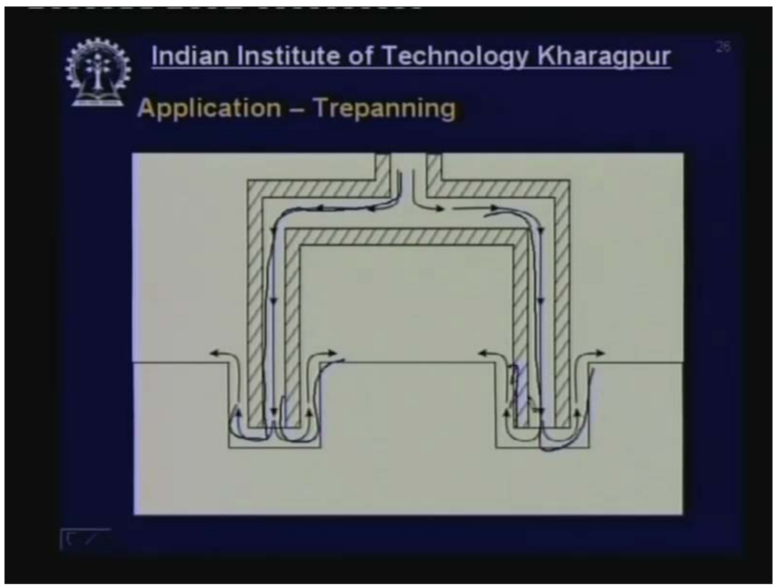

In trepanning, you want to make a large hole and you want to remove the center piece. Technology is very similar, electrolyte is forced to this and once again here also you can put insulation and this way, very large holes can be trepanned. Now let us come to the quiz part it.

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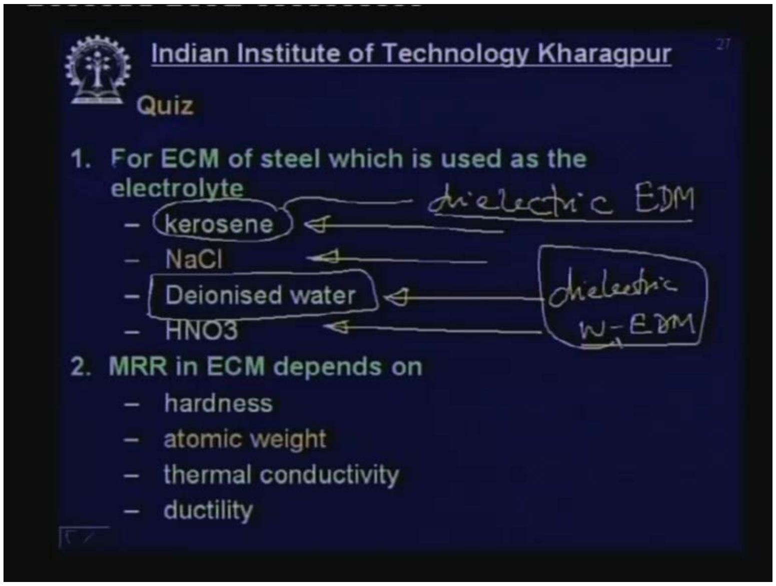

Quiz part of any of these lectures are very interesting. They are not exactly knowledge base things. You need not have to memorize things to answer these quizzes. It has been designed in such a way you can reason it out. So let us come to our first question. What is our first question? For electrochemical machining of steel, so my work material is steel what has to be used as an electrolyte? What are the options? Options are kerosene, sodium chloride, deionised water and nitric acid which one should be used? We already know that kerosene is typically a dielectric medium and it is used as a dielectric medium in electro discharge machining. It is not going to ionize very easily. You require much higher voltage to ionizing.

So kerosene is definitely not used as an electrolyte, deionised water this is not tap water. Deionised water is once again a dielectric and it is used in wire EDM. So as because this is dielectric as because it is deionised it does not have so much ions. So it will not ionize easily. It requires higher ionization potential, so do not use it. So ultimately you are left with sodium chloride or nitric acid both of them can be used as an electrolyte. But, nitric acid as such reacts with most of the material very very violently. So you cannot control the anodic dissolution. So, your choice is ultimately sodium chloride not nitric acid. So in this way for most of the questions you can reason out and get to the correct answer.

Let us come to the second one. Material removal rate in electrochemical machining depends on. We know electrochemical machining process can be very easily modelled by Faraday’s laws of electrochemical dissolution. You also know electrochemical machining process is non-traditional machining process. So the material property, mechanical properties of the material does not really matter. So, what are the options given? Hardness; Hardness of a material is very important in conventional machining say turning milling but it is does not matter as per as electrochemical machining is concerned. The third option given is thermal conductivity. Thermal conductivity quite often is important in nontraditional machining process. We need not throw it away, but if the basic process is thermal process is thermal in nature, then only thermal conductivity comes into picture. Otherwise thermal conductivity does not have any role.

Say for example; in laser machining thermal conductivity will play a role. In electro discharge machining, thermal conductivity would play a role. But as we know electrochemical machining is a electrochemical dissolution. Thermal conductivity has no role in that. Next one is ductility. Ductility plays a role in conventional machining processes as well as mechanical nontraditional machining processes. So in electrochemical machining there is no role. So we are left with atomic weight. Why atomic weight? Why is it important? Why is it is? The answer because we know electrochemical dissolution follows Faraday's law of electrochemical dissolution. Faraday's law and that says your mass of dissolution is proportional to charge and it is also proportional to electrochemically equivalent which is nothing but atomic weight upon valency. So definitely this is the correct answer. MRR in electrochemical machining does depend on atomic state or atomic weight. Now let us go to the third and the fourth question.

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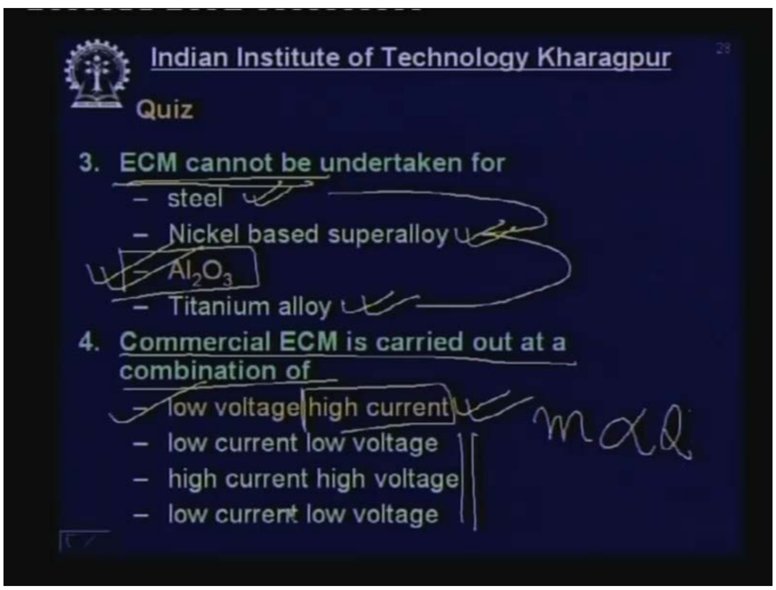

ECM cannot be undertaken for, four options are given: steel, nickel based superalloy, aluminium oxide and titanium alloys. Out of those four options, steel is a metallic alloy and it conducts electricity. So electrically conductive, nickel based superalloys though they are thermally their thermal properties are very high your that the thermal conductivity is very poor. They are electrically conductive same goes for titanium alloy though they are thermally thermal conductivity is less but they are good electrical conductors. So these three things can definitely be machined because one of the basic requirement of electrochemical machining is that your work material has to be electrically conductive.

So out of the given four options, the three options steel nickel based superalloys as well as your titanium alloy satisfy that criteria. So what we are left with? We are left with only one candidate which is aluminum oxide. We know aluminum oxide is a ceramic. You must be knowing by in this time, this is also used for machining steel. This is used as ceramic inserts and they are electrically insulative. Thus this is the answer as because it is electrically insulating, electrically does not conduct. It cannot be machined under electrochemical machining. So your answer is aluminum oxide.

Commercial ECM: the next question commercial ECM is carried out at the combination of low voltage and high current, low current and low voltage. Out of all these options, low voltage and high current is required is the answer because to do the ionization in a salt solution, you require really low voltage. Why high current is required? The answer is once again m upon m is proportional to Q. Either you pass high current for a short duration of time or very small current over a long duration of time, the first one is definitely economically much more beneficial. So the answer is low voltage which comes from the technology and high current which once again comes from the techno economy view point. Now let us go into the solved problems. Today we are going to discuss three different solved problem which represents the domain of electrochemical machine. The first one is,

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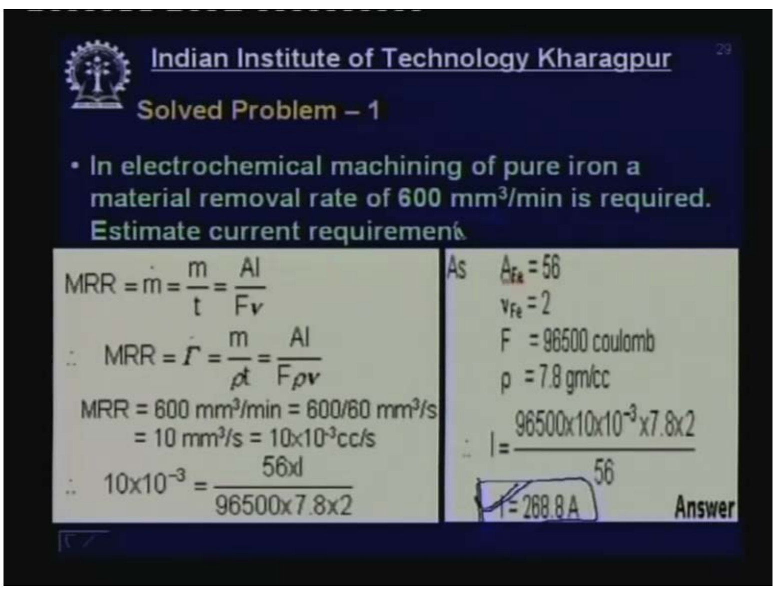

In electrochemical machining of pure iron, so we are starting with the very simple assumption, it is pure iron. A material removal rate of six hundred millimeter cube per minute is to be obtained or is required. Estimate the current requirement. So the estimation is very simple. We know MRR is nothing but, is proportional to atomic weight current and valence and Faradays constant. So from that if we put those values this is in cc per second. So, it comes here material removal rate fifty-six is the atomic weight of iron. 96500 is the faradays constant, eight points seven point eight milli eight is the gram per cc is the density and two is the valence of dissolution of iron. So, using this expression you can very simply get a current of around two hundred sixty-eight point eight ampere. So there are two things to learn from this particular example. What are they? One is how much amount of current is required? It is around 270 ampere. There is another thing to learn. It also indicates how much is the material removal rate which is typically six hundred millimeter cube per minute. We have two more problems and we will go into them gradually. Next this is a bit more difficult problem composition of nickel base super alloy is given.

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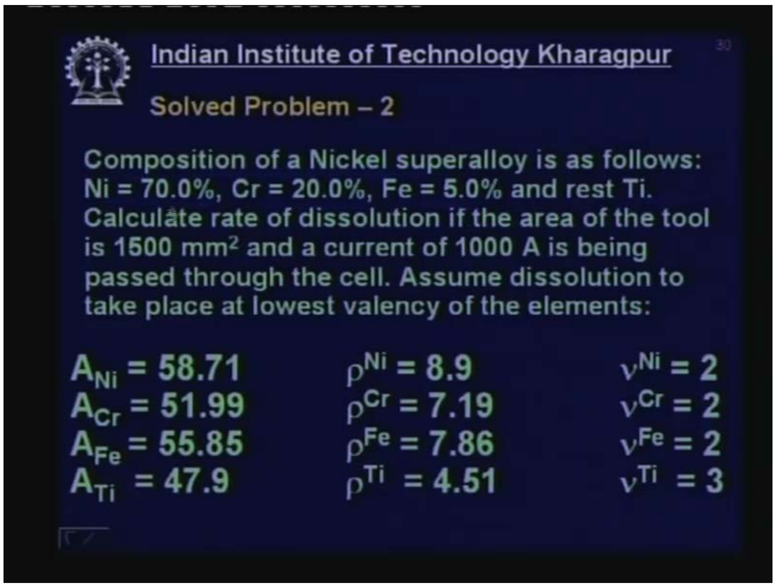

So it is it is having nickel chromium iron as well as titanium. Their percentages are given their densities are given, their atomic weights are given, even there valance of dissolution is given. All these things are given. So what we need to calculate first is their density.

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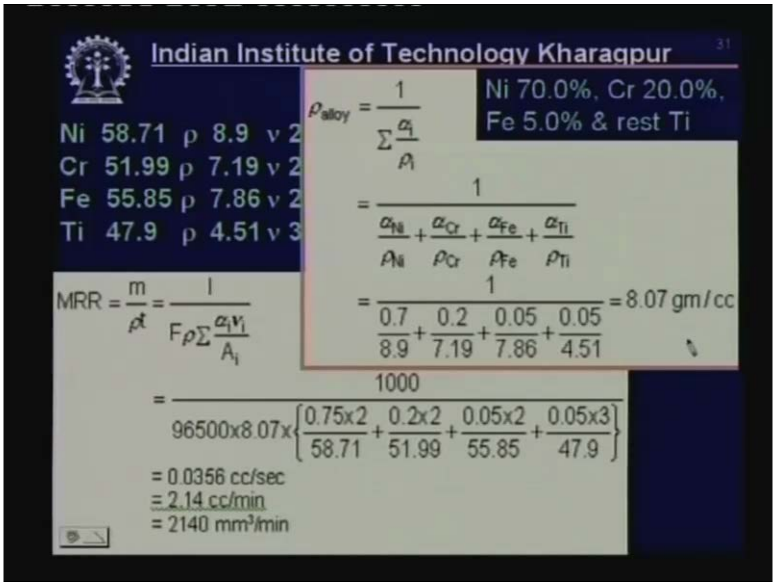

What is the density of the alloy? Density of the alloy has been calculated using this particular expression. Once the density is density is known, density of the alloy is known using the standard expression of material removal rate. I can get the value of material removal rate as two thousand one hundred forty millimeter cube per minute and what is the rate of resolution in that problem, the area was given area was given as fifteen hundred millimeter square. So I can also get the rate of dissolution is around one point five three millimeter per minute. Now let us go to the third problem.

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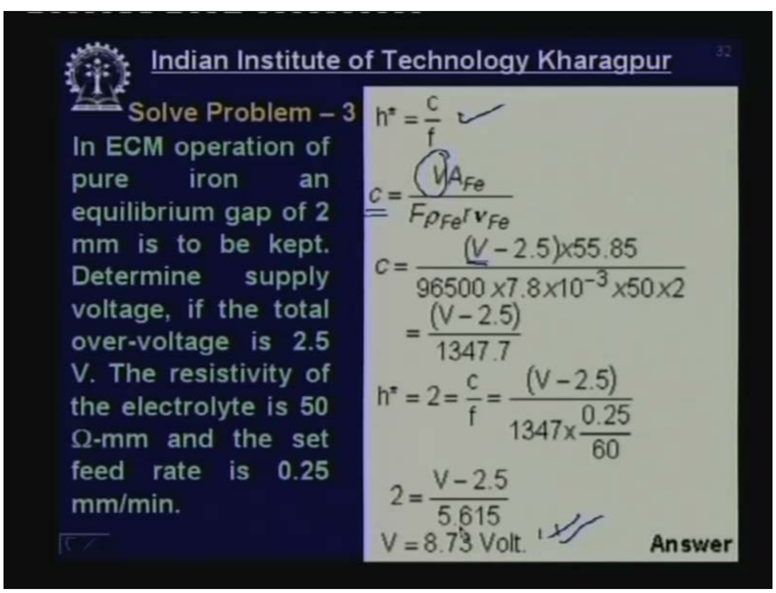

In ECM operation, it says pure iron an equivalent gap of two millimeter is to be kept. Determine the supply voltage, if the over voltage is 2.5, resistivity is given as well as set feed rate is given. So how do you solve the problem? ‘h star’ we have to find out that expression ‘h star’ is the equivalent gap which is c upon f. c we can calculate because all the parameters are given, but it has to be calculated as a function of f. So function voltage applied which is v minus 2.5. In this way, you can find out how much is the voltage applied which is 8.73. Here in this particular problem, there is only one area where you may face problem which is this. This is the voltage; over voltage was given as 25 volt. So the actual voltage is v minus 2.5 volt and from that expression, you have to get the actual voltage. So let us come to the summary of today’s lecture.

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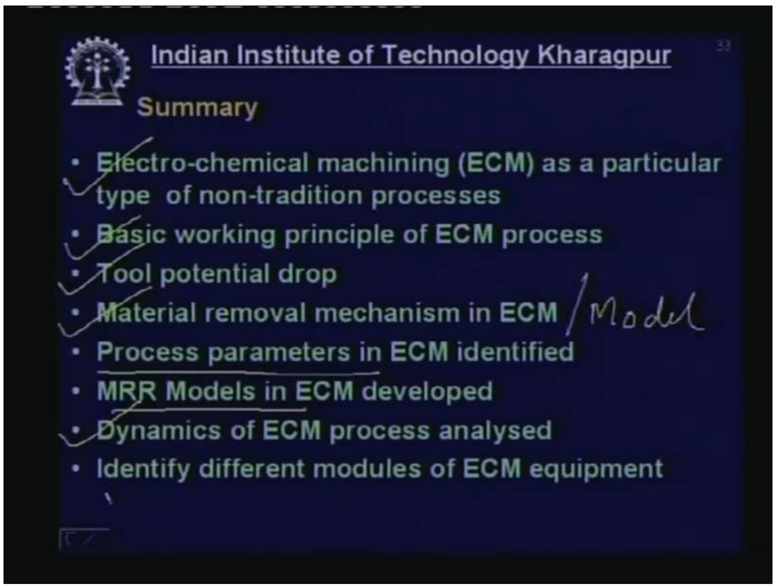

We have already gone through the electrochemical machining process and now you can associate electrochemical machining as a non-traditional machining process. You have also understood the basic working principle of the electrochemical machining process. You can draw as well as find out what are the different potential tool potential drops. You know the material removal mechanisms of electrochemical machining as well as you can model it that is very very important. You know what are the process parameters, models have been developed, dynamics of ECM is very very important that has been analyzed and another important area is different modules of ECM equipment has been talked about along with typical applications. So with that we come to an end of today’s lecture.

Thank you so much.