Advanced Machining Processes
Professor Vijay K. Jain
Department of Mechanical Engineering
Indian Institute of Technology, Kanpur
Lecture 08

So in the last lecture I discussed with you the basic principle of Electrochemical Machining which is based on Faraday's Laws of Electrolysis, we discussed two basic laws of Faraday's Laws of Electrolysis based on which we can calculate the amount of material removed for the given current, chemical equivalent of the anode material and machining time.

I also discussed with you the ECM machine tool, power source and I was discussing with you the electrolyte cleaning and supply system, so we are today I am going to discuss again with the electrolyte cleaning and supply system and I will be completing it.

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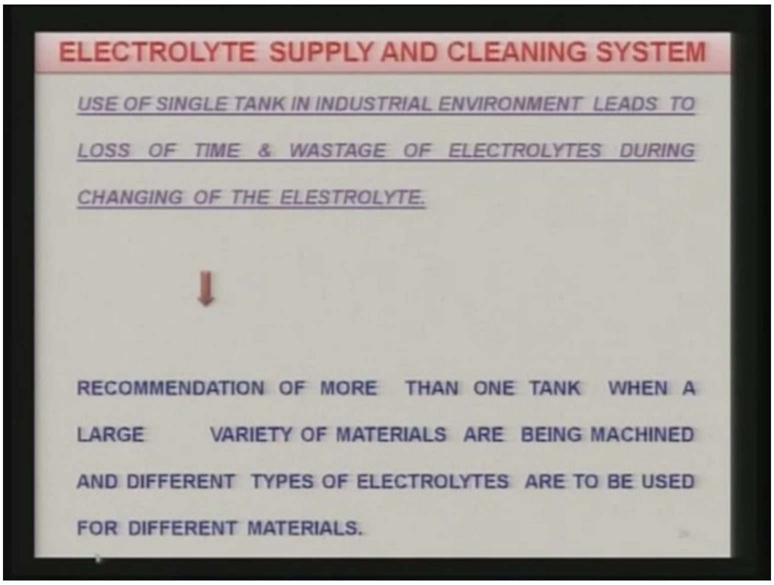

Electrolyte supply and cleaning system, normally small scale industries they use single tank in industrial environment that leads to loss of time and wastage of electrolytes during changing of the electrolyte because there are various kinds of materials or anode materials of which the work pieces are made and for different kind of materials sometimes you may require different type of electrolyte in that case you have to waste whole of the existing electrolyte and fill the tank with the new electrolyte.

To avoid such kind of wastage of electrolyte, money and minimize the time, many industries specifically medium scale industries and large scale industry they prefer to have more than one tank and different tanks they store different type of the electrolyte, so recommendation of more than one tank when a large variety of materials are being machined and different types of electrolytes are to be used for different materials that is very useful, economical and higher productivity it will give you.

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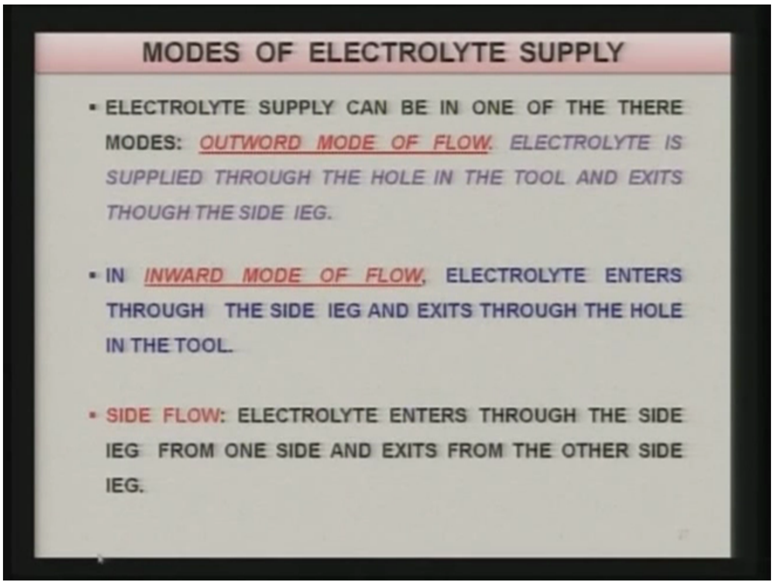

Now modes of electrolyte supply this is something very important, how to supply the electrolyte in the inter electrode gap or the gap between the tool and the work piece. Electrolyte supply can be in one of the three modes as I am going to show with the help of figures also outward mode of flow, electrolyte is supplied through the hole in the tool and it exits to the side inter electrode gap as I will show you the figure in the following slide.

Second mode of electrolyte supply is inward mode of electrolyte flow, electrolyte enters through the side inter electrode gap and it exits through the hole in the tool and third mode of electrolyte flow is known as side flow, in this case electrolyte enters through the side of inter electrode gap, through side inter electrode gap, from one side and exits from the other side. In all the three cases you will see later on that the profile of the anode obtained is different slightly different from each other.

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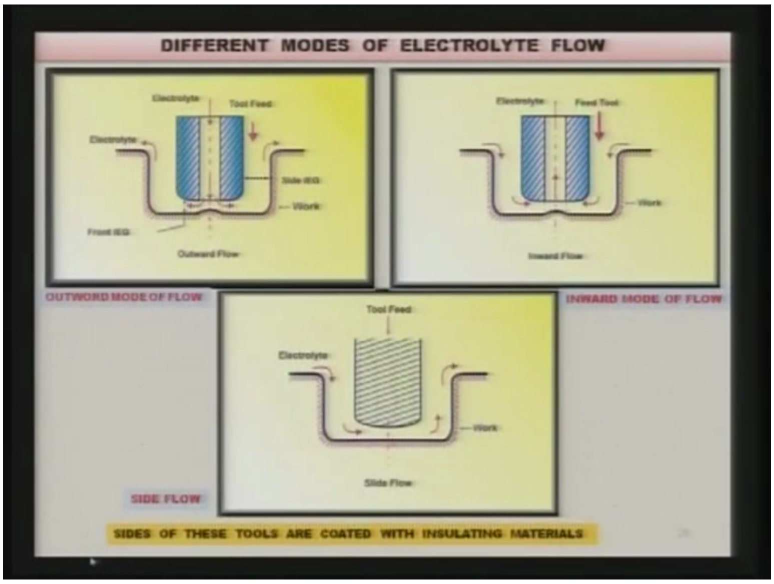

Now let us see, this is the outward mode of electrolyte flow as you can see as I mentioned in the earlier slide that electrolyte is entering through the center and it exits from the sides. In the second one inward mode of electrolyte flow, electrolyte is entering from the sides and it is exiting from the central hole of the tool and in the third case as you can see the electrolyte is entering from one side and it is exiting from the other side of the tool so all the three, in all the three you can see the entry and exit points of the electrolyte are different.

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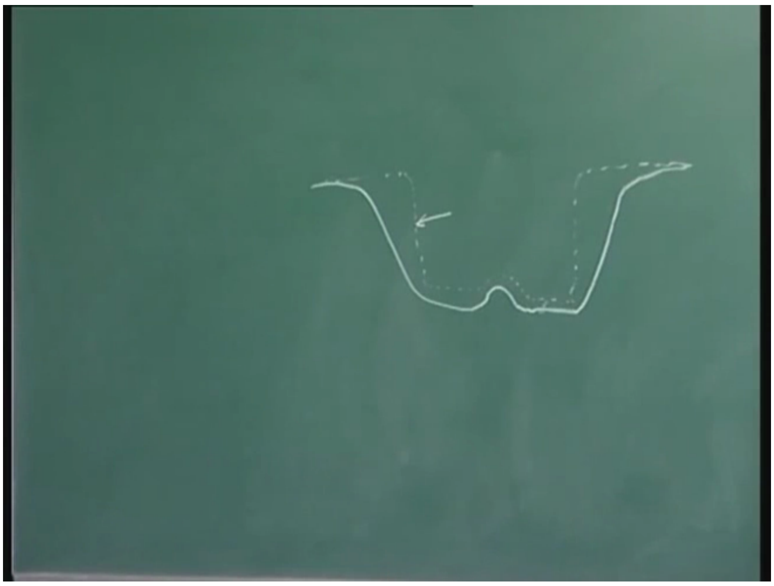

Sides of this tools are coated with insulating material one point is to be noted that the sides of the tools are coated with the insulating material that is why you will find that the sides of the whole machine are straight rather than tapper which you get normally with the bare tool as I will show you that if you have the bare tool then the side of the hole drilled will be something like this but in the present case since the sides of the tool are coated with the insulating material you are getting this kind of the shape of the anode profile.

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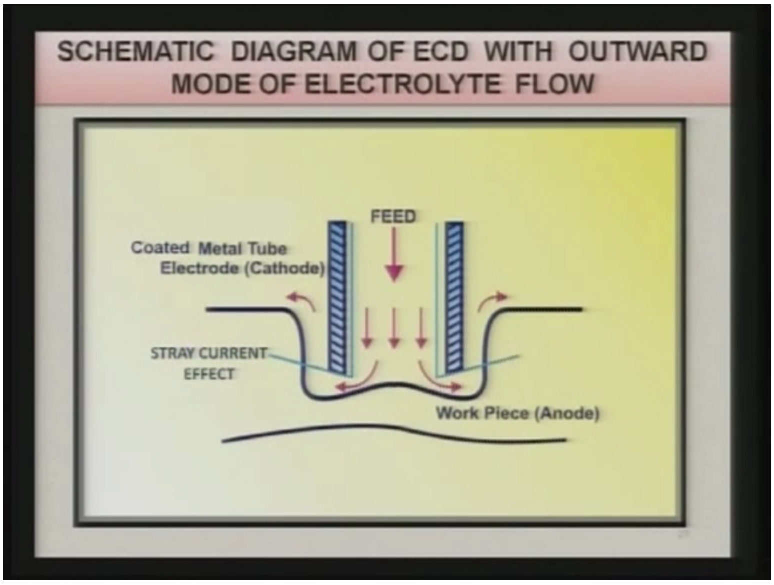

Schematic diagram of electrochemically drilled, the electrochemical drilling with outward mode of electrolyte flow as I mentioned in this particular slide you can see here the coating is clearly shown over there and this is the outward mode of electrolyte flow, the tool is entering through the center of the central hole in the tool, electrolyte is entering through the central hole of the tool and it is exiting from the side of the hole now you can clearly see there is some stray current effect that is why you are not getting the flat surface at the ends and they are slightly tapered.

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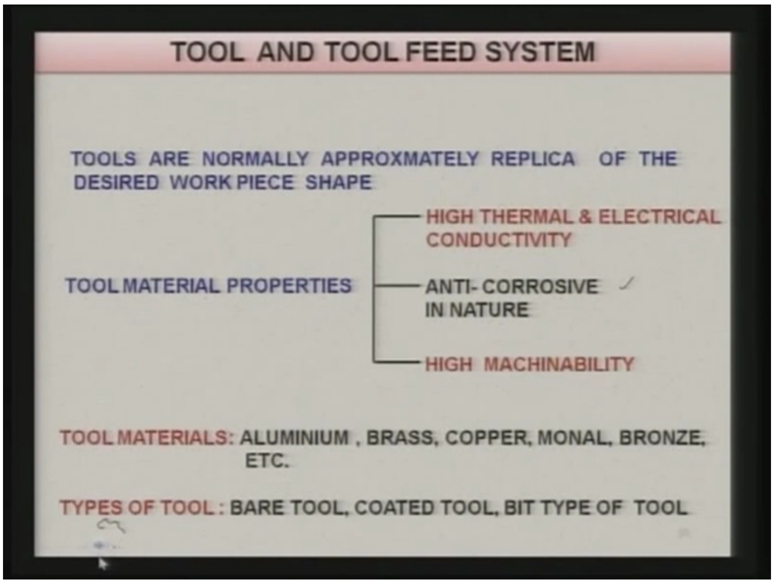

Now another thing is tool and tool feed system this is another sub system which is very important, tools are normally approximately replica of the desired work piece profile this is approximate for exact profile of the hole you have to use proper tooling design technique which I will discuss later on.

Tool material, selection of tool material is very important, you can see some of the properties of the tool material are like high thermal conductivity and high electrical conductivity both are important thermal conductivity is important so that the temperature of the electrolyte does not rise to a higher level otherwise the conductivity of the electrolyte is going to change as a result of that whatever tool you have designed for the desired surface profile or desired work piece surface profile, you will not get it because conductivity has changed or it is different than what you used at the time of designing the tool.

Same way electrical conductivity of the tool material is also important and it should be high otherwise if electrical conductivity is low then you will get higher generation of the heat as a result of that the temperature will rise and then the production or the design of the tool profile as well as prediction of the work piece profile will be different.

Another important point is anti-corrosive nature of the tool material because these tool and work piece both are immersed inside the electrolyte and most of this electrolyte are corrosive in nature and if the tool material is not anti-corrosive then the tool itself will get corroded, eroded, its shape and size will change and you will not get the desired profile and dimensions of the work piece cavity or work piece surface.

And another important point as long as tool material properties are concerned is high machinability specially when you want to machine a complex shaped component before machining you have to make the tool of complex shape and to make the tool of a complex shape the tool material should be easily machinable otherwise you cannot machine or make accurately the shape and size of the tools so high machinability of the tool material is another desirable important property.

Normal tool material which are used in ECM are aluminium which has all these properties like high thermal conductivity, high electrical conductivity, anti-corrosive in nature and easily machinable. Same is true with brass, copper, monal, bronze, etc. So depending upon the cost other considerations you can choose one of these materials as the tool material which is to be used in ECM.

Type of the tool there are three types of the tools which are in practice one is the bare tool, another is the coated tool and third one is the bit type of tool I will explain all the theory later.

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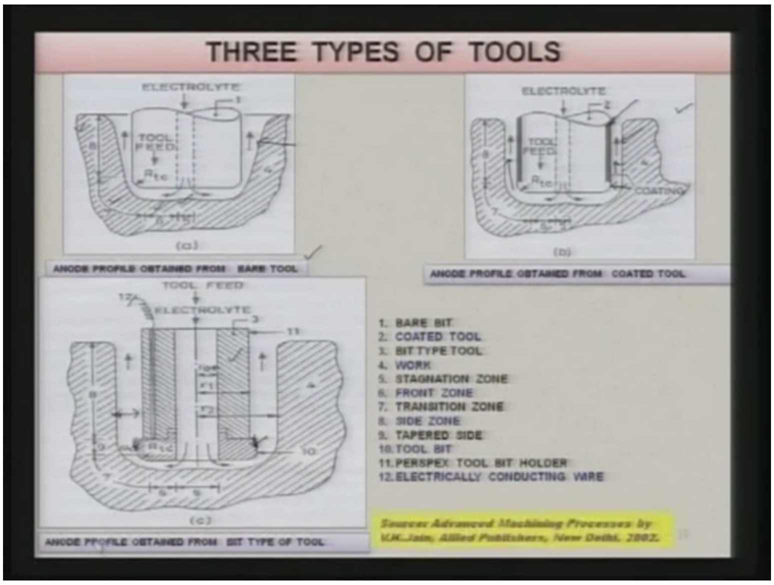

You can see these are the different parts that I am going to show here this is the anode profile obtained from the bare tool, important point here is the tool is the bare that means it is not coated from the sides, say here if this is the tool then there is no coating on the sides also there is no coating at the bottom part of the tool (())(10:29 to 10:36 - inaudible) and you can see one is the bare tool and here four is the work piece, five is the stagnation zone, this is known as the stagnation zone and six is known as the front zone, seven is known as the transition zone and eight is known as the side zone.

Now you can see the difference between these two figure, here the tool used is a coated tool you can see the coating over here shown with the dark color and as a result of this coated tool on the side you can see the difference in the profile in the side valve of coated tool and bare tool, they are very clear one is the tapper another is the straight sided.

One very important point to note here is that at the bottom of the coated tool this is a bare part and this bare part gives you additional over cut and because of this additional over cut the electrolyte is able to low through the side gap as you can see over here electrolyte is able to go out through the side gaps if this side gaps is not there or if it is very very small then you will require very high pressure to push the electrolyte out of the machining zone.

You can see here clearly the bottom part is bare corner also is bare means uncoated and small part of the end of the tool is also bare so that you get additional over cut. Now third one is known as bit type of the tool now there are certain problems with this also which is the coated tool.

Once the tool gets damaged you have to through out the whole of the tool and making of the tool, material of the tool are quite expensive comparatively. So what people have done instead of making the whole tool of the metal what they have done they have made a bit (()) (12:38 to 12:46 - inaudible) joined together with the help of nut and screw kind of the arrangement.

As you can see over here this is the bit of the tool which is made of electrically conducting material and whatever is the portion over here this is bare you can coat it also if you want to minimize or reduce the overcut in the side gap as you can see here this is the over cut in the side gap and this can be reduced by coating this particular part on the sides sorry coating this particular tool on the side. Now this part is made of perspex known as tool bit holder and these are the, twelve is the electrically conducting wire which are going to give the connection to the positive terminal or negative terminal of the power supply.

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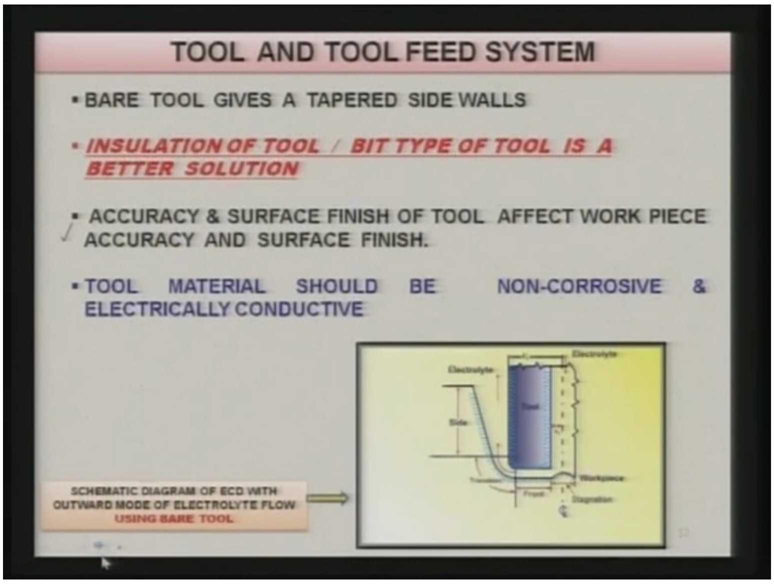

Now next one you can see here bare tool gives a tapered side profile as I have shown to you or side wall, tapered side walls and this gives a clear cut idea here in this particular figure what kind of side walls you are going to get with the help of the bare tool as shown over here. Insulation of the tool or bit type of the tool is a better solution as I have already mentioned.

Accuracy and surface finish of tool affect work piece accuracy and surface finish, this is another important point to note that whatever is the accuracy of the tool and whatever is the surface finish of the tool that is reflected on the work piece, so to have a better surface finish on the machine component, you should have better surface finish on the tool and same is true for the accuracy or the tolerances on the tool which will result the tolerances on the work piece. I have already mentioned that tool materials should be non-corrosive and electrically conductive.

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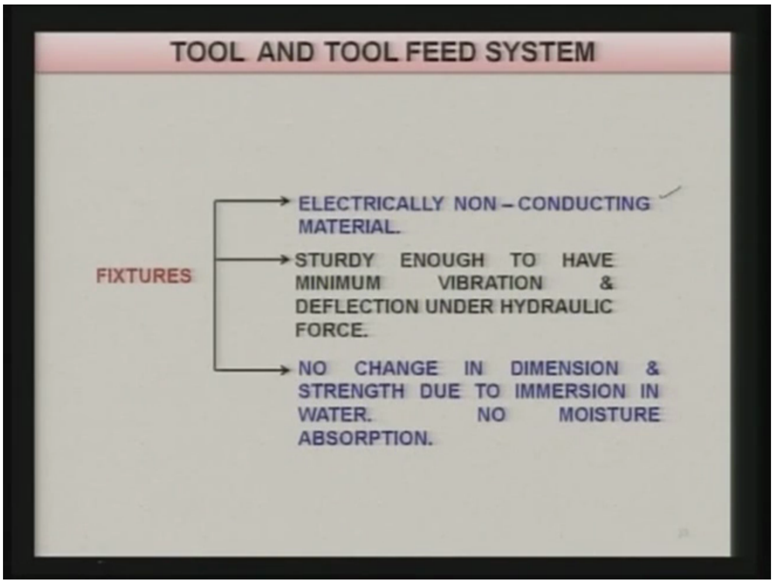

Now tool and tool feed system, fixtures for holding the tool should be made of electrically non-conducting material otherwise your system is not going to work properly and the fixture for tool holder or tool holding should be sturdy enough to have minimum vibration and deflection under hydraulic force because lot of hydraulic forces are going to act on the tool during electro chemical machining process so your fixture should be sturdy and it should have minimum vibration what will happen if vibration is there.

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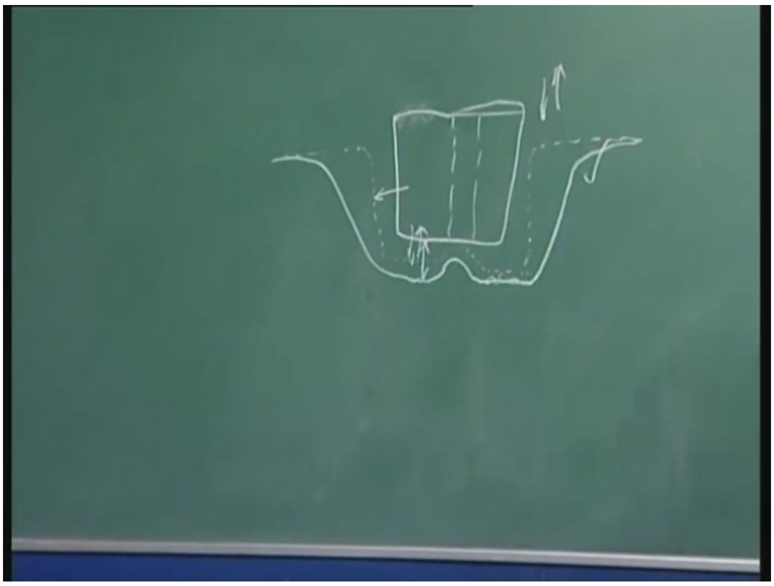

Let us see if vibration is there then suppose this tool is vibrating if the tool is vibrating then the gap that is known as inter electrode gap is also going to change and if inter electrode gap is going to change then material removal rate will keep changing with time and that will create the problem will not get the shape and size of the work piece that you have designed.

No change in dimension and strength due to immersion water should take place, no moisture absorption should be there because if the dimensions and strength of the fixture of the tool change then it will affect the overall accuracy and tolerances achieved on the work piece surface.

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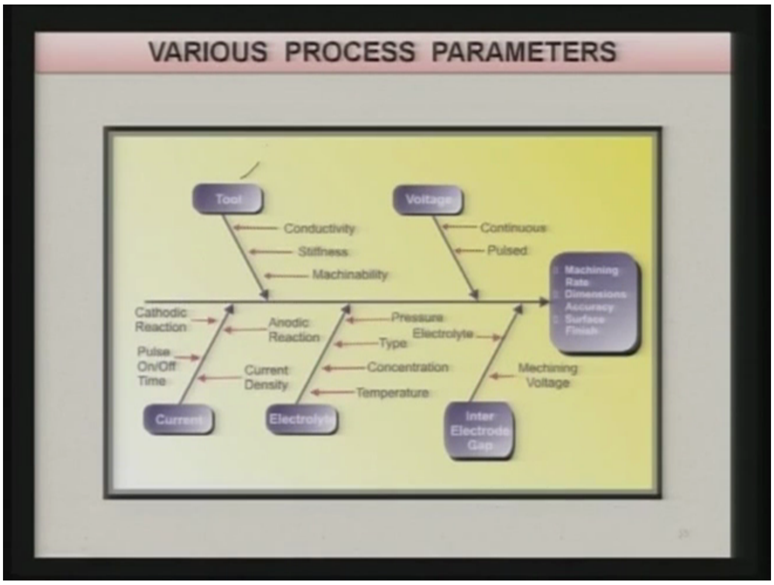

Now let us what are the various sector that are governing the anode profile during ECM. This is the fishbone diagram which tells you what are the various factors which affect the process performance and machine component, tolerances, dimensions and surface finish, we start with the tool. Tool conductivity, electrical conductivity, thermal conductivity of the tool material, steepness of the tool, machinability of the tool how easily it can be machined so that you can produce complex shapes on the tool to get them on the work piece, another parameter is the voltage whether you are using continuous volt or pulsed volt both will give you different kind of the accuracy.

Then current whether is a pulse current or continuous current if you are using the pulse voltage then you will have pulse on time, pulse off time, then there are the cathodic reactions which will be controlled by the magnitude of the current, anodic reaction again will be controlled by the magnitude of the current and current density is very very important parameter it is going to decide what is going to be the material removal rate and that to some extent also affects the final accuracy of the machine component.

Electrolyte is another important parameter, pressure at which the electrolyte is being supplied is important because depending upon the pressure and inter electrode gap as well as the cross sectional area of the inter electrode gap they are going to decide the velocity with which the electrolyte is flowing in the inter electrode gap and that velocity will decide how fast it can remove the sludge and other contaminants from the inter electrode gap and because more the contamination less will be the current flow during that particular period.

So this pressure with which the electrolyte is supplied also is an important parameter. What is the type of electrolyte? Because as I have mentioned already it can be the neutral or salt type of the electrolyte there can be the acidic type of electrolyte there can be the alkaline electrolyte they will give different material removal rate and different accuracy.

Concentration of the electrolyte is another important parameter and definitely temperature of the electrolyte is another very important parameter because by changing the temperature the conductivity of the electrolyte is changing, by changing the concentration of the electrolyte the conductivity of the electrolyte is changing and if electrolyte conductivity is changing then definitely material removal rate is changing.

And another last parameter is the inter electrode gap and inter electrode gap, what is the machining voltage across the inter electrode gap is another important parameter. Now after having known these various parameters which are affecting the performance of the process, accuracy of the machine component, how are you going to evaluate the performance of the process?

So there are certain process based on which you can evaluate the performance of the electrochemical machining process or for that matter any other process as well so those parameters are like machining rate what is the machining rate we can write or we can evaluate the machining rate in three different ways just like as follows.

It can be evaluated as MRRG where the units will be gram per second that means how many grams of material is being removed from the anode in each second or you can evaluate it in terms of MRRV that is the volumetric material removal rate, how much volume of the material is removed in one second, you can represent it in terms of millimeter cube per second or you can have MRRL that is the linear material removal rate or you can understand it that it at what rate the tool is moving towards the work piece and this is represented in terms of millimeter per second. So you can represent it in one of the form at different occasion you have to use one of these three ways of representing material removal rate.

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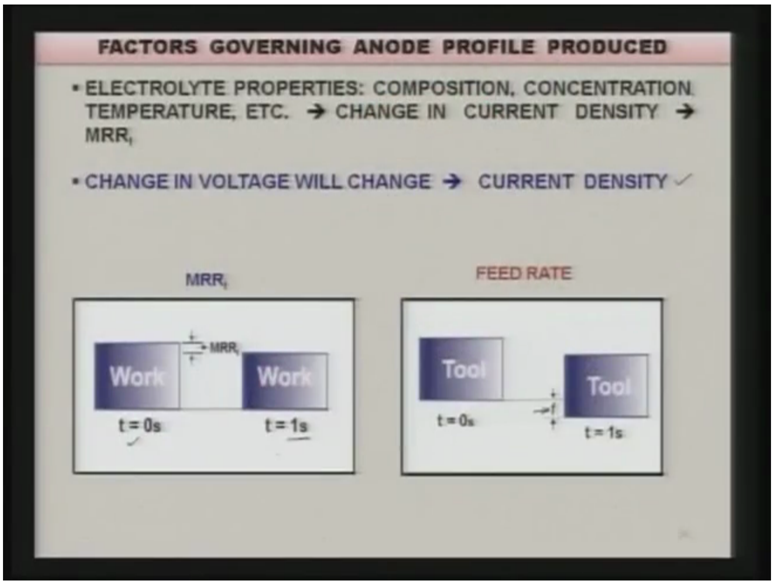

So I have already explained what are the various factors that are governing anode profile produced they are electrolyte properties like composition of the electrolyte, it is not necessary always that you always use a single type of electrolyte.

Many researchers have used mixture of two types or more than two types of the electrolyte so you should know clearly what are the properties of that mixture of the electrolyte specifically the electrical conductivity of the electrolyte, then concentration of the electrolyte, temperature, etc. because this is going to control the current density in the inter electrode gap change in voltage will change the current density.

Now let us understand this, this is very important the linear material removal rate as you can see here initially at time T is equal to 0, this is the size of the work piece after time T is equal to 1 second, the work piece has recessed by this amount which return here as MRRL and that is what I have written there that linear material removal rate in terms of millimeter per second so it has moved this much distance in 1 second.

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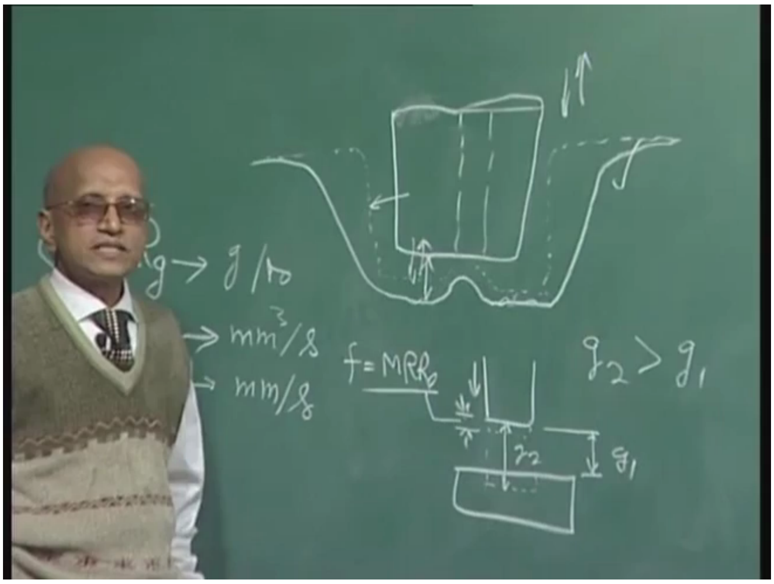

Same way once this has moved this much distance in 1 second then as I mentioned in the last class that if it is like this and this is the initial inter electrode gap in after 1 second the work piece surface has recessed this much so the gap will increase this one, G1 and G2 and G2 is bigger than G1 so to maintain the constant gap you have to feed the tool downward that is why the tool will come over here and this distance by which it is moving downwards should be equal to MRRL.

So to maintain the constant gap the feed rate should be equal to the linear material removal rate then only you can maintain the constant inter electrode gap so that is what I have shown here that the tool must move F and that F should be equal to the MRRL if you want to maintain the constant inter electrode gap.

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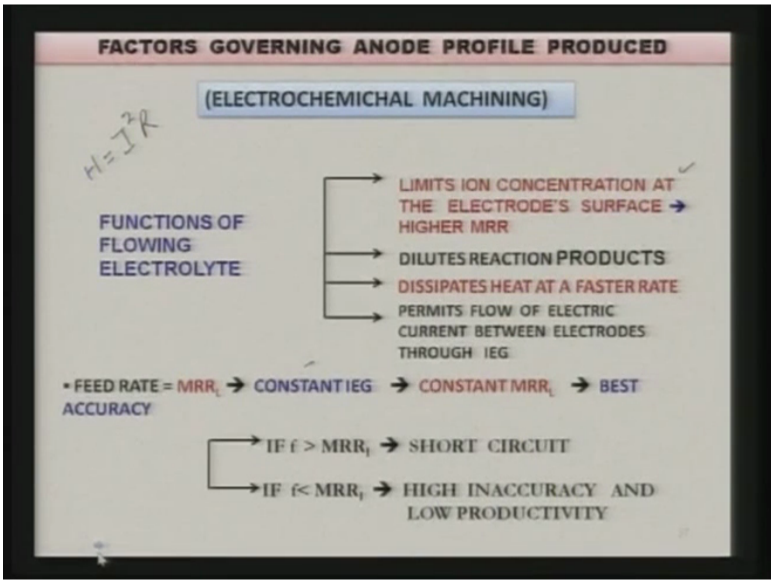

Functions of flowing electrolyte, electrolyte is flowing at a high velocity in the inter electrode gap. What are the various functions performed by the electrolyte in the inter electrode gap? First one is it limits ion concentration at the electrode surface, this is another important because if ion concentration is there then current flow rate will reduce so for higher material removal rate we want higher current to flow or higher current density and for that purpose the concentration should not be there at the, at either of the two electrodes.

And electrolyte flowing also dilutes the reaction product because once electrolyte is flowing it takes away the reaction product, gases, etc. along with it out of the machining zone and once they are taken out of the machining zone, fresh electrolyte is continuously coming in, so that you will be able to get constant electrical conductivity of the electrolyte that is in the inter electrode gap.

It dissipates heat at a faster rate I have mentioned already that during ECM heat is generated and that heat can be calculated by I square R where I is the current flowing in the inter electrode gap and R is the resistance of the medium or the electrolyte in the inter electrode gap you can calculate the heat generated and in many cases this heat generation is quite high so that is why we need the electrolyte to flow at high rate so that it does not change the temperature of the electrolyte substantially.

Electrolyte flow permits flow of electric current between electrodes through inter electrode gap if it is not flowing then whole of the inter electrode gap will be occupied by the sludge and other reaction products and the conductivity of the electrolyte will substantially reduce as a result of that flow of current practically will stop.

Feed rate as I have mentioned that should be equal to MRRL to obtain the constant inter electrode gap, if feed rate is greater than MRRL, what is going to happen? Short circuit will take place let us understand what is going to happen here. In this particular case the feed rate is greater than MRRL than really what is going to happen this gap is going to continuously reduced because this is moving at a faster rate than this surface is recessing downward as a result of that a point will come when short circuit will take place, so this is undesirable condition we do not want that feed rate should be greater than MRRL otherwise short circuit will take place.

If feed rate is smaller than MRRL that is also not desirable otherwise high inaccuracy and low productivity will be obtained because this gap will keep increasing continuously and if this gap keeps increasing continuously current density will reduce as a result of that material removal rate will also decrease.

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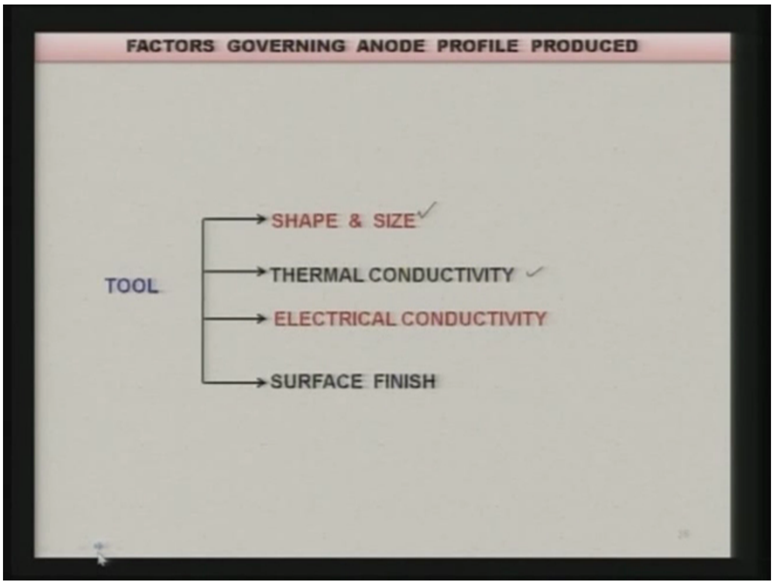

What are the various factors that affect the anode profile, one of them is tool shape and size of the tool will directly affect the anode profile and as I have mentioned earlier also that profile produced on the work piece is more or less a replica of the tool so from that point of view shape and size of the tool are important.

Thermal conductivity of the tool material is also important, if tool material has high thermal conductivity rise in the temperature in the inter electrode gap of the electrolyte will be low and that is what we really want. Electrical conductivity of the tool material is very important otherwise the resistance will be high and if resistance is high then I square R heating of the tool itself will take place and that will change the temperature of the electrolyte and surface finish of the tool is equally important because there is reproduction, practically reproduction of the surface finish of the tool that you get on the work piece surface other than other things.

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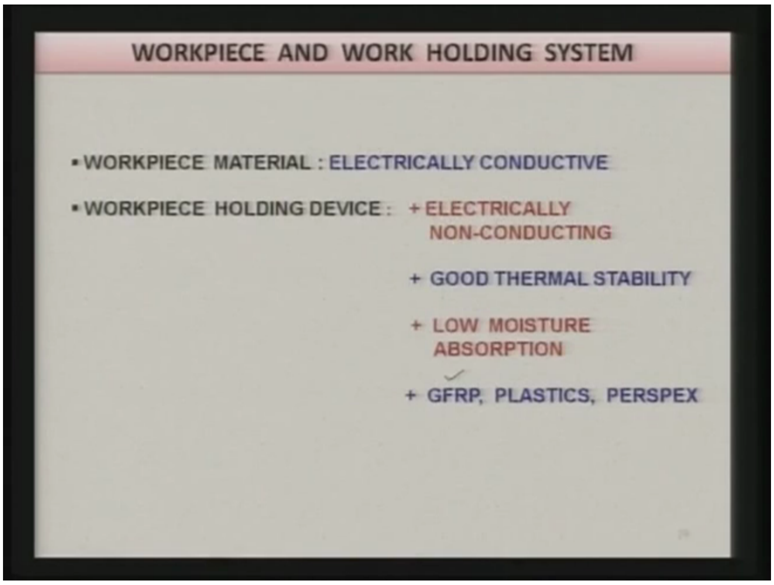

Work piece material should be electrically conductive this is the first and foremost important condition for electrochemical machining, electrochemical machine cannot machine electrically non-conductive material that point you should keep in mind, work piece holding device it should be electrically non-conducting otherwise current will pass through the work piece holding device and work piece holding device itself will start dissolving as a result of that the your fixture tooling, etc. will get damaged or will disappear after a certain period of time because of dissolution as anodic material

It should have good thermal stability it should have low moisture absorption this is another important point that work piece holding device should have minimum moisture absorption otherwise once they start absorbing the moisture their dimensions will keep changing and then as a result of that the work piece dimensions you will not be able to maintain.

Some of the materials which can be used as the wok piece holding device glass fiber reinforced plastic that is GFRP, plastics perspex materials are another one which can be used for this purpose.

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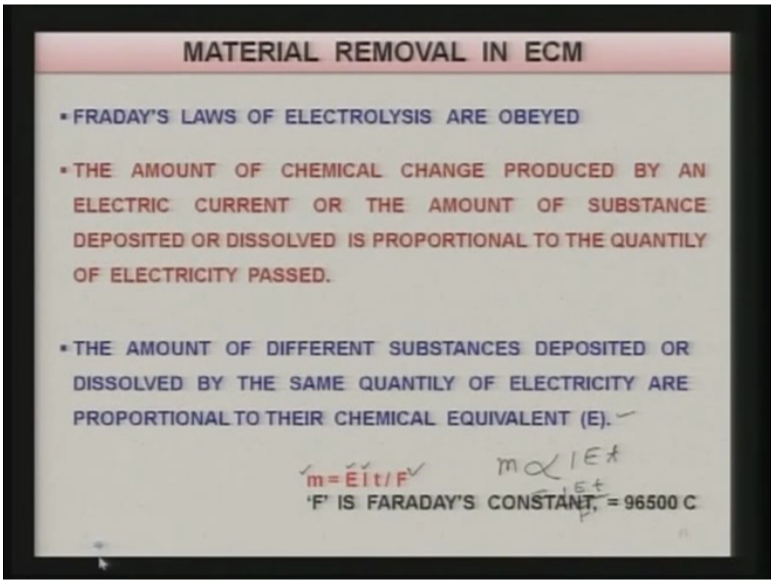

Now we know from all this discussion what are the various factors or parameters that are going to affect the performance of the process. Can, how many of them can be incorporated in the mathematical model with the help of which we are going to evaluate material removal in electrochemical machining, let us see.

Material removal in ECM is based on Faraday's Law of electrolysis, the amount of chemical change produced by an electric current or the amount of substance deposited or dissolved is proportional to the quantity of electricity passed. The amount of different substances deposited or dissolved by the same quantity of electricity are proportional to their chemically equivalent that is E.

Now this is the important basic equation which is derived from the laws of Faradays laws of electrolysis as you can see here this, the amount of material dissolved in time T, E is the chemical equivalent of the anode material not the cathode material that is given over here. I is the current flowing in the inter electrode gap for time T and we know that M is proportional to IET.

Now there is a constant that is known as Faradays constant F, so we can write this equation equal to M equal to IET over F where F is the Faradays constant and that is value we will, I will tell you Faradays constant its value is 96500 coulombs.

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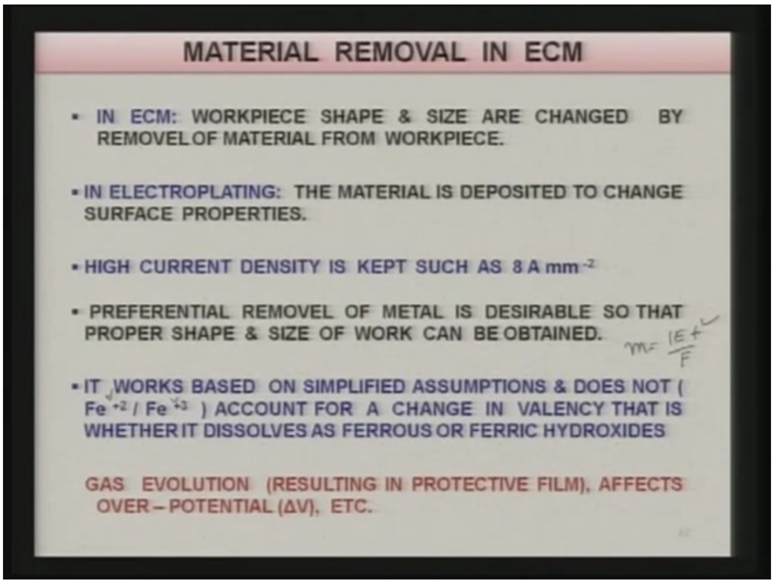

In ECM work piece shape and size are changed by removal of material from the work piece, in electroplating the material deposited to change surface property, so you can see both them are following Faradays laws of electrolysis but one is just reverse of the other.

In ECM material is being removed while in plating or electroplating material is deposited, in ECM material is removed from the anode and in electroplating material is deposited on the cathode whatever material is removed from the anode the same material is deposited on the cathode.

High current density is kept as high as 8 ampere per millimeter square in case of electrochemical machining. Preferential removal of the metal is desirable so that proper shape and size of work piece can be obtained. It works based on the simplified assumptions, this equation which I have written in the last slide that is IET over F it works on the assumption, various assumptions, simplified assumptions, and it does not account for a change in valency this is very important point to note that it does not account for the change in valency whether iron is dissolving at 2 valency or it is dissolving at 3 valency depending upon the valency it will form either ferrous hydroxide or ferric hydroxide.

So this is another weakness of this particular equation which is derived from the Faradays laws of electrolysis and it also does not take into account anything about the gas evolution and we know that at the cathode hydrogen gases evolved and at the anode oxygen gas is evolved and it affects over potential also and it does not account for over potential as well.

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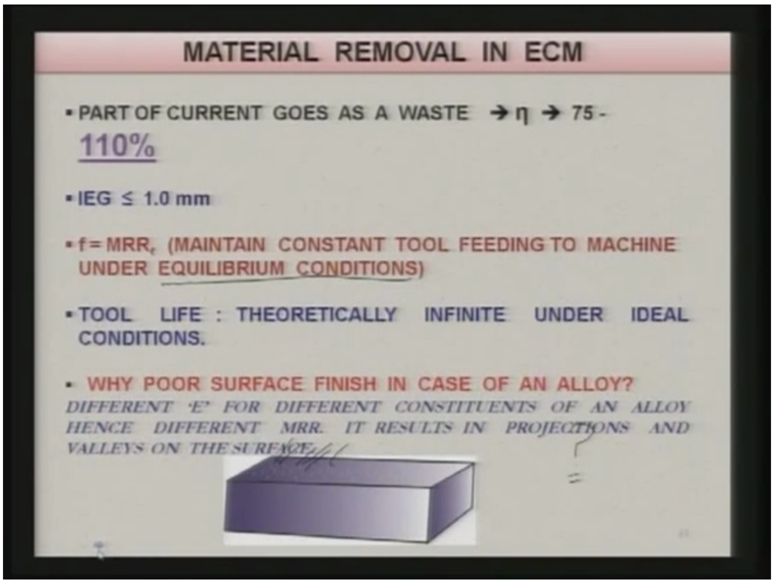

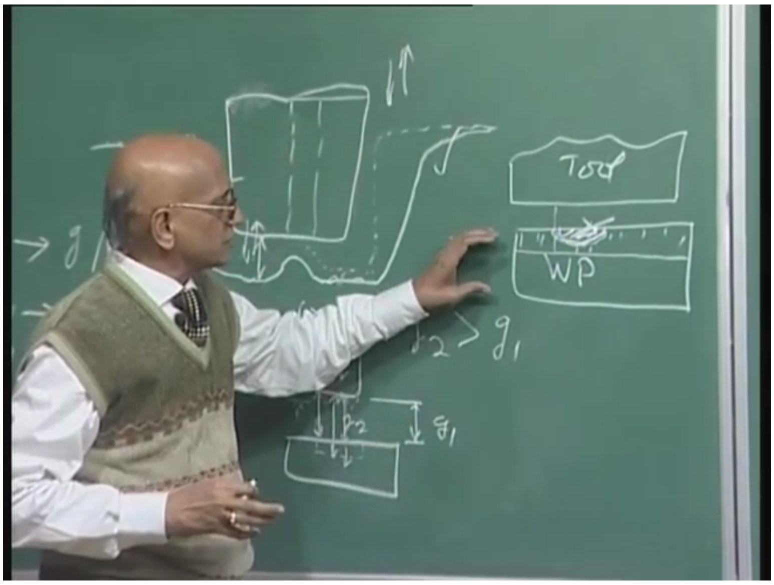

Now when we evaluate the efficiency of the ECM process normally it should be less than 100 percent but sometimes it is found that efficiency comes out to be more than 100 percent which is something non understandable, how does it happen let us see if you take a case of machining a flat path and suppose you are machining it through ECM process, this is tool, this is work piece.

Suppose this is a casting and this casting has got a electrically non-conducting point or sand particles or some other electrically non-conducting point but what will happen that this will remove the material from this part like this and this material without getting dissolved it will come out because surrounding material has dissolved.

As a result of this when the mass of this machine component is taken then really current has not been utilized for dissolving this particular of the sand particle or non-conducting particle that is why the efficiency of obtained becomes greater than 100 percent which is in my opinion fictitious because of such kind of the inclusions inter electrode gap is normally kept less than or equal to 1 millimeter.

Feed rate should be equal to linear material removal rate from the work piece it is important to maintain constant tool feeding to machine under equilibrium condition there is another new term that is the equilibrium condition and this equilibrium condition is obtained when the inter electrode gap is equilibrium gap and you should maintain that equilibrium gap by keeping feed rate equal to linear material removal rate.

Tool life theoretically is infinite under ideal condition which I mentioned in the last class also, now normally when we machine the materials with the help of the ECM process most of the time they are not pure metals, they are alloys and when you are machining an alloy you do not get a good surface finish this is very important why you do not get a good surface finish, let me explain it very clearly with the help of a figure.

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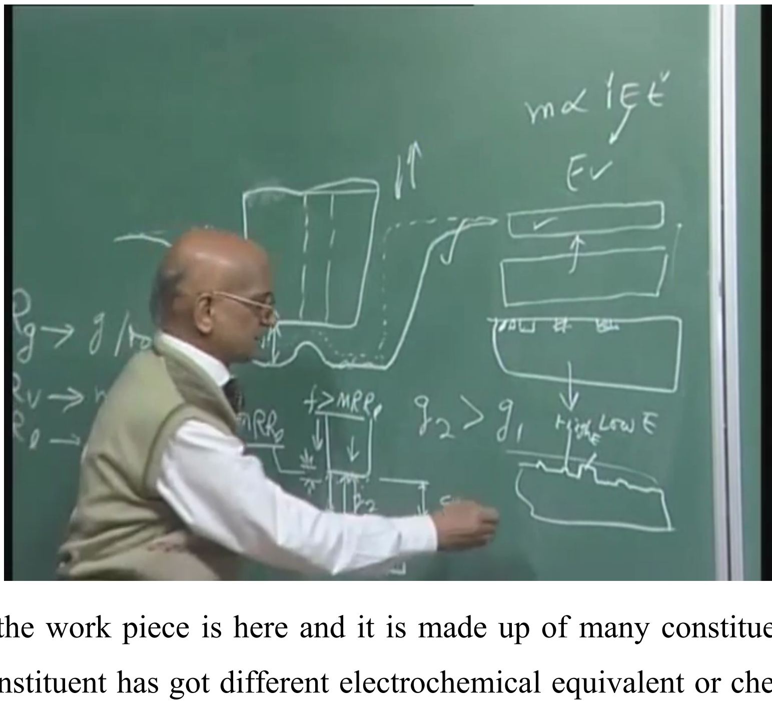

Suppose this is the work piece is here and it is made up of many constituents like this and each of these constituent has got different electrochemical equivalent or chemical equivalent that is given by E what will happen each of these constituent by the same current will be dissolved to a different height as a result of that when they are dissolving because their material removal rate is different which depends upon E because if we see here, M is proportional to IET and I is constant, T is constant but this E is different for different material.

So what will happen that when it is machined at a zoomed view or a magnified view you will find that surface is like this, this has got low value of E, this has got high value of E and so on depending upon the value of E you get different heights of the peaks or the surface that you are getting over here.

That is why the surface roughness of this particular machine component will be very poor compared to the pure metal, had this been pure metal then the kind of the surface that you should have obtained suppose this is the work piece and after machining you will get the surface like this compared to this, this will have much better surface finish compared to this particular alloy.

That is why in case of alloy you do not get good surface finish and this is what is shown over here if you see projections are shown over here and this projections led to different heights of different constituents of an alloy. So different E that is chemical equivalent for different constituents of an alloy hence different material removal rate, specifically linear material removal rate it results in projections and valleys on the surface of different height and depth.

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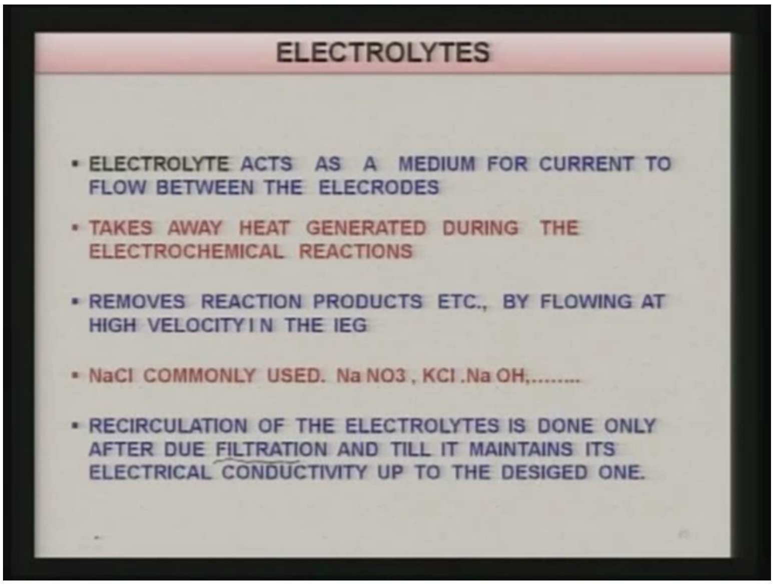

Electrolytes and mechanical properties of electrochemically machined components, electrolyte acts as a medium for the current to flow between the electrodes that I have already mentioned that between the tool and the work piece over here as you can see here is, this is flow of electrolyte so this electrolyte over here makes the medium for the current to flow.

Takes away heat generated during the electrochemical reactions, it removes reaction products, etc. by flowing at high velocity in the inter electrode gap. Sodium chloride is most commonly used electrolyte however sodium nitrate, potassium chloride, sodium hydroxide are, there are many other types of the electrolytes which are used in electrochemical machining, it depends upon which is the work piece material or anode material.

Recirculation of the electrolytes is done only after due filtration and till it maintains its electrical conductivity upto the designed value, now this is very important because electrolytes are quite expensive you cannot through them out after using them once so invariably in all plants electrolytes are re-circulated but they should be properly filtered otherwise they will block the inter electrode gap or they will change the conductivity of the electrolyte in the inter electrode gap both are undesirable so you have to maintain the conductivity of the electrolyte as constant during the electrochemical machining process.

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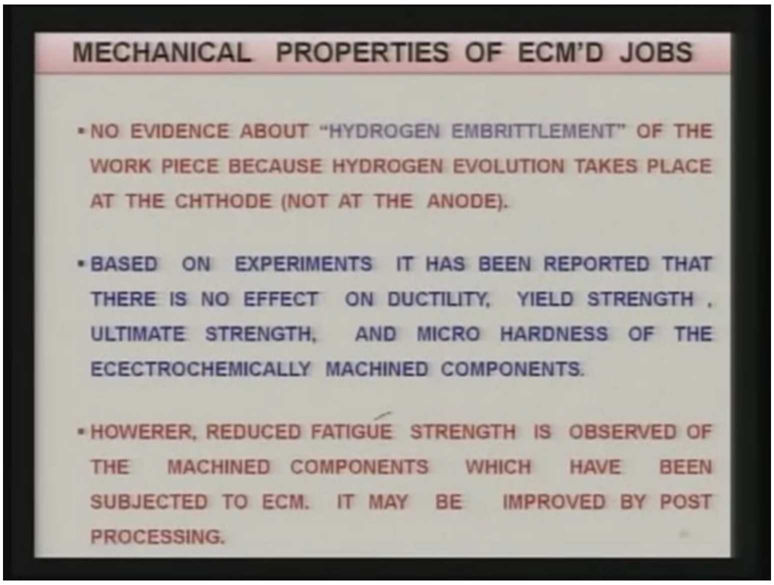

Mechanical properties of the electrochemically machined components or jobs, there are no evidence in the literature available about hydrogen embrittlement of the work piece because hydrogen evolution takes place at the cathode not at the anode, this is very important as I have mentioned earlier also that hydrogen evolution is taking place at the cathode and oxygen evolution is taking place at the anode.

So no evidences are there of hydrogen embrittlement of the work piece material. Based on experiment it has been reported that there is no effect on ductility of the machine component or the anode material, the no change in the yield strength or ultimate strength and micro hardness of the electrochemical machine components and this is obvious also because there are no mechanical forces that are applied on the work piece surface which could change the mechanical properties of the machine component.

However reduced fatigue strength is observed of the machine component which have been subjected to ECM, this is another important point that after ECM or electrochemical machining the fatigue strength of the component reduces the reason is very simple if you are machining any component.

Suppose you are machining this particular component here and normally there are the compressive stresses that are on the, that are in the sub surface of the component and when you are machining and you are removing these layers from there then the layers which we are subjected for the compressive stresses or which we are having the compressive stresses they are removed from the final component as a result of that compressive stresses are minimized or removed completely and that is why the fatigue strength of the component goes down. Now however the fatigue strength of the machine component can be improved by post processing.

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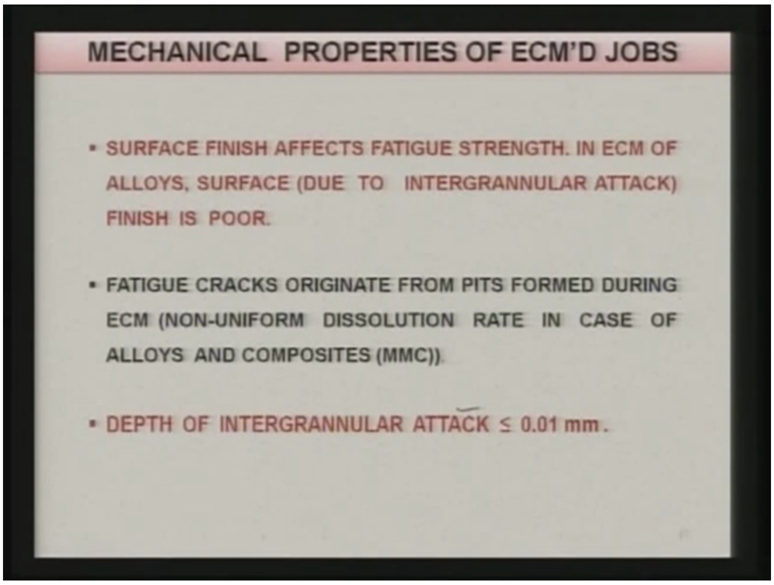

Surface finish affects fatigue strength in ECM of alloys surface due to intergrannular attack finish is poor and this also affects the fatigue strength of the machine component because attack on the intergrannular boundaries during ECM removes more amount of material from the boundary and it forms micro pits and due to those micro pits the fatigue strength of the component reduces.

Fatigue cracks originate from pits formed during electrochemical machining and non-uniform dissolution rate in case of alloys and composites that is the metal matrix composites, depth of intergrannular attack is normally equal to or less than 10 micro meter that is 0.1 millimeter and these are the main regions or main causes of reduced fatigue strength.

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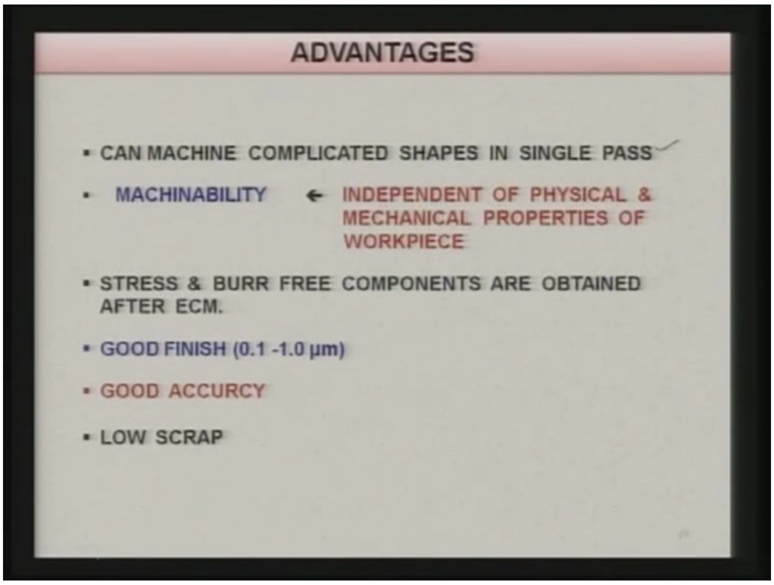

Now let us see in brief what are the various advantages and some of the important application of electrochemical machining process. It can machine complicated shapes in single pass this is very important advantage that very complex shapes say take the case of turbine blades which is 3 dimensional complex shaped component, whole of the turbine blade can be machined in single go or one go and it has really very very complicated shapes.

Machinability is independent of physical and mechanical properties of the work piece, now this is another advantage because when we discussed in the very first lecture I mentioned that hardness and strength of the newly developed materials is main barrier in the improvement of the productivity that is why researchers started thinking of evolving the processes which can machine or whose performance is independent of the mechanical properties of the work piece material.

So electrochemical machining is one of the advanced machining processes where the performance of ECM is independent of mechanical properties of the work piece material, stress and burr free components are obtained after ECM they are the no stresses developed during ECM because no forces are acting temperature is slightly higher than the room temperature so chances of production of residual stresses are minimum and there are no mechanical forces no shearing no deformation hence burr formation is not there so the machine surface are free of stresses and burrs.

Reasonably good surface finish can be obtained which ranges between 0.1 to 1 micro meter, it is the function of the machining parameter and the properties of the work piece material as I have mentioned sometimes that if it is an alloy, you are not going to get very good surface finish, if it is a pure metal yes you are going to a good surface finish.

Reasonably good accuracy you can achieve by ECM however the accuracy of the machine component depends upon how well you have designed the tool and whether you have taken optimum machine conditions or not. Scrap value is low, once you have designed correct tool and you have said the optimum parameters these ECM machines are kind of CNC machines where you can set various parameters most of the things are controlled automatically so you your rejection rate goes down substantially that is why you get the low scrap and operations are automatic.

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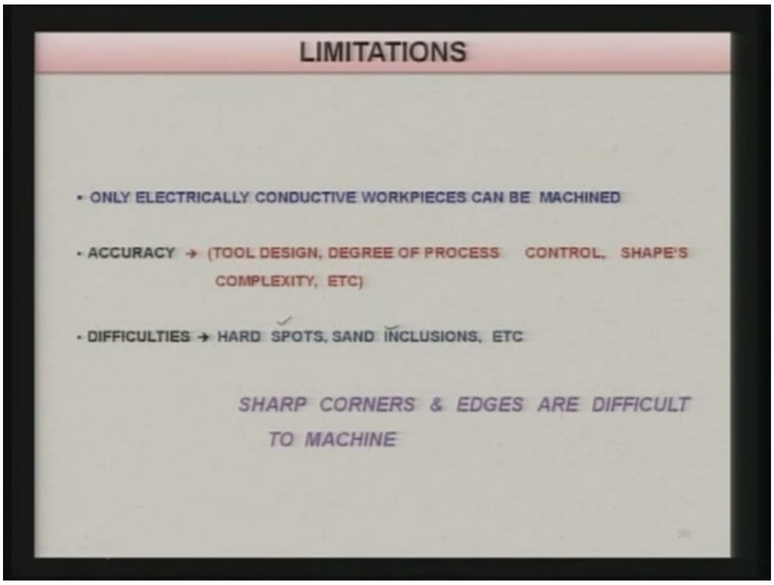

However there are certain limitations which we should know and which are very important that they can machine only electrically conductive work pieces not electrically non-conducting work pieces. Accuracy of the machine components depends on tool design which is really a comparatively though task, degree of process control, how well you can control the different machining parameters especially the current, inter electrode gap, voltage, contamination of the electrolyte, temperature of the electrolyte and so on.

Shapes complexity, how complex the shape will also decide the accuracy because it is well known that in ECM you cannot produce very sharp corners so that also affects the accuracy of the machine components.

Machining of hard spots, sand inclusions, etc. are very important and very difficult as I have mentioned that why do you get more than 100 percent machining efficiency it is because of the hard spots or sand inclusion which are if hard spot is electrically non-conducting than that is going to create the problem and it may lead to the machining efficiency more than 100 percent and I have just mentioned that production of sharp corners and edges are difficult while machining by ECM process so this is another limitation.

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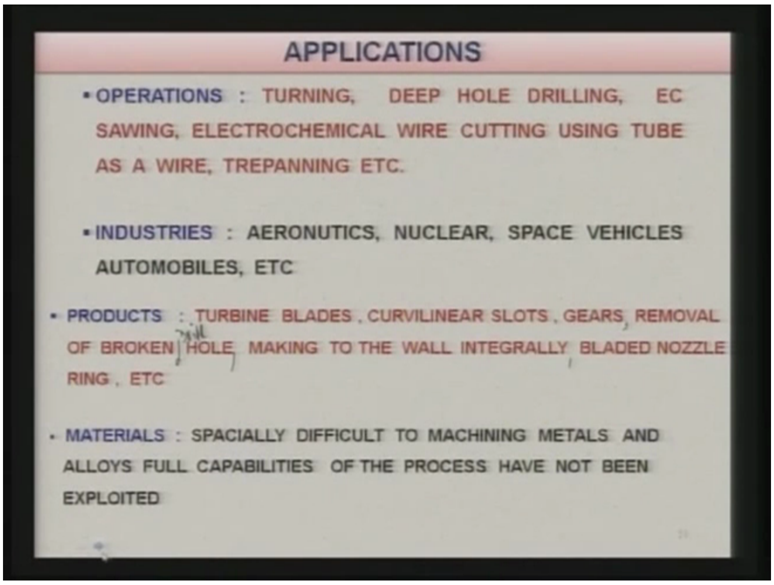

Now let us see the application, this particular process can be applied for turning operation, electrochemical turning, deep hole drilling, electrochemical sawing, electrochemical wire cutting using tube as a wire, trepanning operation etc. I have already shown you the figures related to them and this particular product is used in the industries such as aeronautics, nuclear power plant, space vehicles automobiles etc. and specific products for which this particular process is commonly used are turbine blades, curvilinear slots, gears or removal of broken gears and then removal of broken hole, broken tip or broken drill from the hole, removal of broken drill from the hole, making of wall integrally bladed nozzle ring, etc.

Materials for which it can be applied are specially difficult to machine metals and alloys however it is felt that full capabilities of the process have not been exploited one of the main reason being that people are having fear that it is not very environment friendly process and disposal of sludge etc. is another problem with this particular process because of which their its full capabilities have not been exploited.

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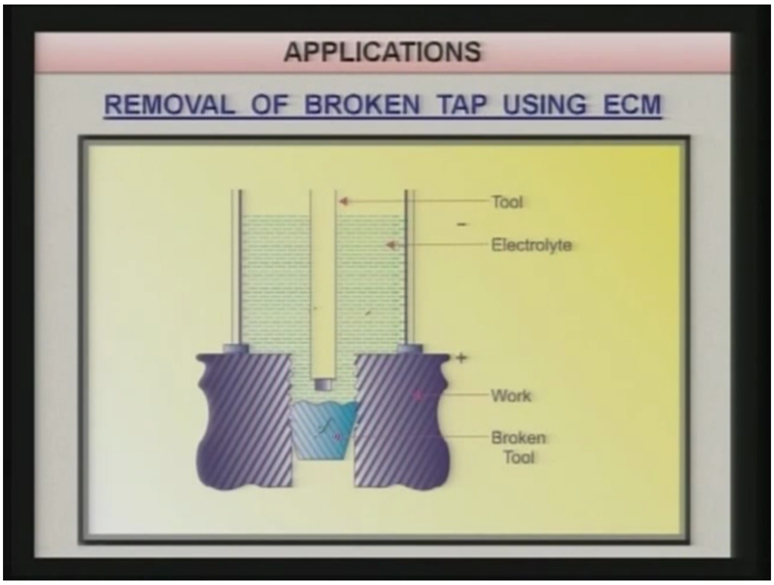

Let us see some of the figures with the application aspect as you can see here is the broken tool and this broken tool you have to remove from the hole this can be easily done by this ECM process as you can see tool is there it will make a hole over there in this particular broken tool and electrolyte is there you make this one as the anode and this one as the cathode and drill a hole inside this and once you drill the hole then you take it out by rotating the broken tool.

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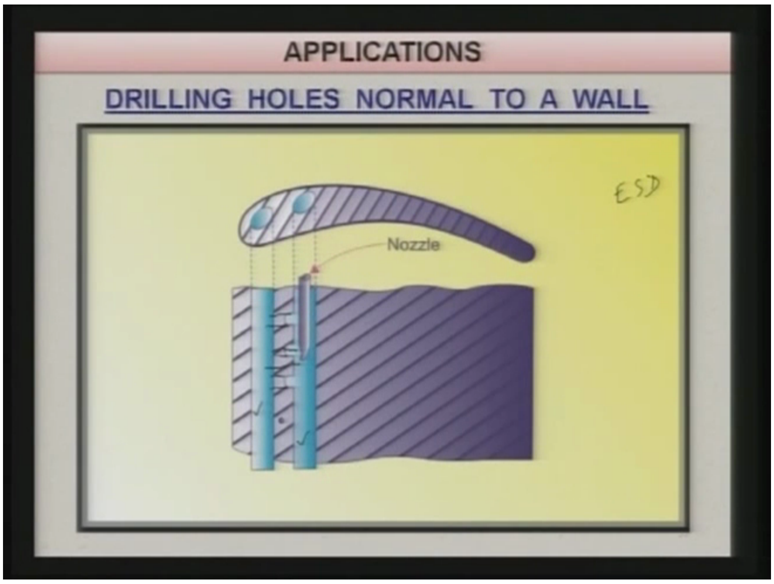

Now this is very important application now say this a turbine, there is a blade or some other component where you have the two holes, one hole is here another hole is here and this is the solid wall now suppose you want to drill a hole normal to this wall how to do it, no process either traditional or non-traditional can do these kind of the holes except the process that is electrochemical drilling process.

The very specific name of this is electrostream drilling ESD and you can see here that there is nozzle from this nozzle electrolyte is coming out and this electrolyte will be hitting the work piece or the wall at these particular point and it will go dissolving it and you will find the hole drilled over here throughout or like this and this can be done by ECM only not by other processes.

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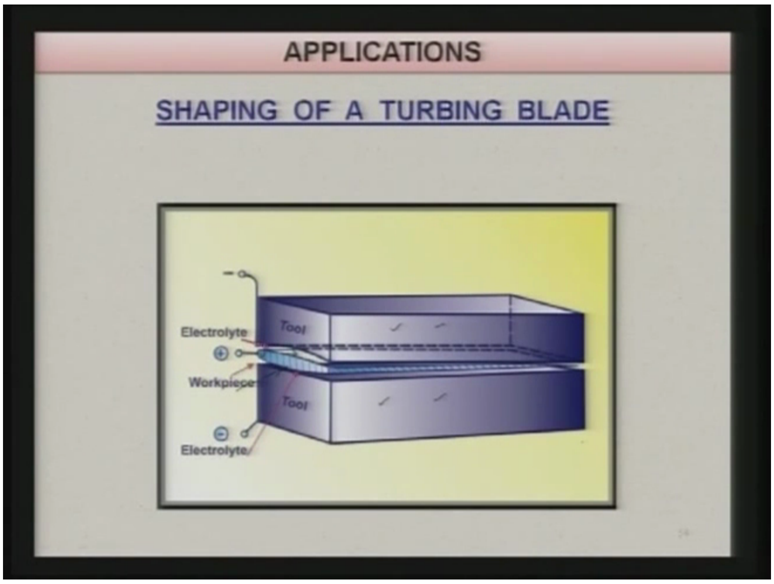

Turbine blades can be machined in single go as you can see here that there are the two tools one at the top another at the bottom and in between the two the turbine blade material is sandwiched and both tools, top and bottom tool part tool have the different shapes depending upon the shape of the turbine blade you make this as the anode and tools are made top and bottom tools are made as the cathode and electrolyte is supplied over there in the gap from the top one as well as the bottom one and you supply very high current to this and you will find after certain period of time you get the desired shape and size of the blade.

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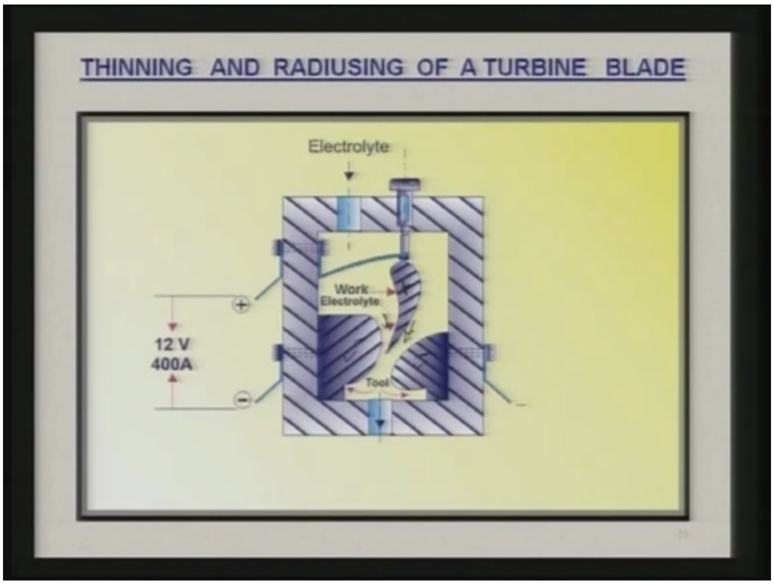

You can see the another configuration of thinning and radiusing of a turbine blade, you can see tools are here two parts for inner one and outer one and electrolyte is flowing through these parts so over here as well as here and this is made as the anode and these are made as the cathode and when current is supplied they are connected as you can see here then thinning of this edge of the turbine blade takes place.

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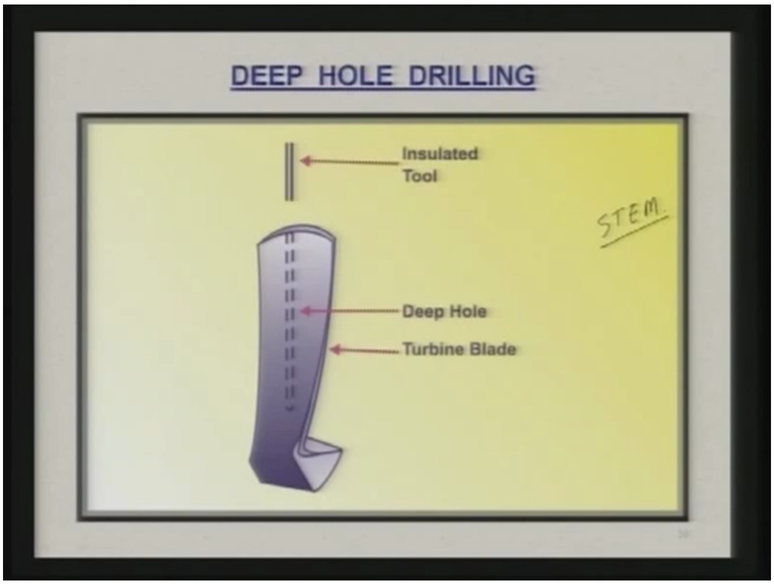

If you want to drill the deep hole in a turbine blade you can see the insulated tool is used for drilling the deep hole such deep holes are very very important and desirable for cooling purposes I will discuss them later on when I discuss the process that is named as shaped tube electro machining at that time I will discuss them in detail. I will stop here, thank you very much.