Advanced Machining Processes
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Design for electrolyte flow & ECM Plant

Hello, and welcome back to this lecture on Microsystems Fabrication by Advanced Manufacturing Processes. So, a quick recap of what we had done in the last class. We were trying to figure out the tool shape on a function mapping basis from the workpiece to the tool. And supposing there is a geometry of the workpiece which is defined by any CAD package in terms of lines, straight lines, curves, different curvatures or for example, fits like Bezier fit or any other B-spline or Hermitian fit. So, the idea is that how you can map by dividing the surfaces into small parts and finding out what is the corresponding negative shape which would be there on the tool surface which would be able to sort of di-sink the whole shape into a workpiece surface. So, we actually did a problem for 2D-based curvature this is illustrated here.

And then we also learned about the fact that the other important issue which actually comes in ECM is the electrolyte flow and the way it has designed. One of the basic fundamentals of electrolytic flow had been seen before when we were talking about designing of the electrolyte velocity between the tool and the workpiece. And we figured out that this velocity is a key component because the amount of heat that is injected into the moving electrolyte by virtue of the electrical power transferred onto the electrolyte from the electrodes has to be equal to the heat dissipated. And there would be equilibrium in terms of a temperature state which is achieved because of this whole process and that temperature should never go beyond the boiling point of the electrolyte.

So, we designed for that and then with that optimum velocity where the temperature just is just below the boiling point we tried to find out what is the active pressure on the electrode. So, that is one aspect that what are the parameters of the flow. But the very important second aspect which will in fact talk today in our lecture is how to place the flow or position the flow or where can be the inlets and the outlets associated with the tool. So, that you can safely carry the electrolyte injection almost always along with the tool as it moves along the surface which has to be machined. And for doing this you know you have to introduce concepts by really looking at the overall design the amount of leftover area of the workpiece based on whatever tool area you are using.

And there would be some very nice illustrations and figures which we will talk about where the flow has to be planned in a manner the flow has to emanate out of the electrode in a manner. So, that full coverage of the workpiece surface can happen. So, the other important aspect is the description of machining plants which would do the ECM process and then we will see the effects of ECM on some other materials of interest. And correspondingly study about some other processes associated with the ECM like the ECG, the electrochemical grinding, the electro stream drilling, ESD and so on so forth. And after all the review of this fundamental level electrochemical machining processes we will then start over again and try to apply some of this technology to the fabrication of microsystems like, for example, microneedles, small very small super fine high aspect ratio structures used for other applications which are almost always used in the area of MEMS or microsystems can be fabricated using such machining protocols by localized deposition of material at a certain place which we will talk about little bit later once the applications slides begin on the applications of chemical electrochemical machining on microsystems.

So, let us look at what we did in the 2D case just reviewing what you know we said in the last few lectures that supposing there is a certain tool surface for example, this is the tool surface also the workpiece surface with the certain topology which is mapped by some function let us say y equal to phi of x and these are all the so-called workpiece and then you want to imprint it or embedded into a sort of looking it at a reverse analogy tool surface. So, in other words, conventionally it is the tool which will embed and produce a die-sinking operation on the workpiece. So, the workpiece moves towards the tool surface we do not know what the shape of this and we will have to somehow estimate the tool shape based on this y equal to phi x relationship for the workpiece shape. And we already know that in such a situation the d phi by dx is or the slope is very important basis for finding out a relationship between yt and yw this point right here is xt yt and the xw and xt which is actually equal to xw plus lambda by f del phi xw by del xw. So, this actually becomes equal to yt by lambda plus lambda by f this becomes equal to xw plus lambda by f times of slope.

So, as we have already seen for the 2D case if supposing yw was related by an equation a plus b xw plus c xw square in that event the slope d phi xw by dxw would be twice would be bx b plus twice c xw. And simultaneously the final equation which would emerge would be corresponding to y equal to a plus bx plus cx and these are all tool coordinates. So, this is the sort of function relationship between the y and x on the tool surface of this point which would map then this surface the tool surface. And this comes out to be equal to a plus bxt plus cxt minus lambda by f minus lambda by f times of b plus twice cxt square divided by 1 plus twice c lambda by f. So, this is how you can correlate the yt and the xt and similar case can be repeated for the 3-dimensional problem.

So, in case the equation of the workpiece is a 3-dimensional equation. So, yw in this case is related to let us say a plus bxw plus cxw square plus some dzw. So, we are including both all the 3 coordinates here the xy and z. So, it is a Cartesian coordinate system d xw d zw plus e zw square plus g xw zw. So, the required tool geometry, which is then calculated in a similar manner, but of course, for the relationship between the yw and xw and yw and zw independently.

So, you will have to do partial derivatives of all these and then find out what is the corresponding relationship on a 3-dimensional plane between 2 points xw, yw, zw and xt, yt, zt in a similar manner as you have done for the 2-dimensional curvature case. So, this is actually a plane surface that we are talking about and how you map that surface into the tool surface. So, this is of more practical importance to the ECM process typically, because all the features or structures that you are trying to die-sink into the workpiece are 3-dimensional surfaces or surface topologies. So, here the final relationship which comes out between the yt xt and x or zt the position coordinates of the tool surface is basically a plus b xt plus c xt square plus d zt plus e zt square plus g xt zt minus lambda by f minus lambda by f of this whole term here which is b plus twice c xt plus gt zt square plus d plus twice e zt plus g xt square divided by the term 1 plus twice c plus e lambda by f. So, that is how the 3-dimensional relationship would exist between the yx and z on the tool side if a given relationship.

So, called yw in terms of some function f of xw, zw exists. So, you have to really look at in the same manner following the same algorithm as we have done before for the curvature case and I leave it for food for thought for you guys to be able to see how you can derive the tool equation on this 3D surface or how you can map the topology of a workpiece surface topology of a workpiece onto the tool surface using such a you know fundamental equation given here in this slide. So, some of the important points to remember particularly when we talk about this so-called ECM process that it should be remembered that the method used to solve for y value is typically applicable for smooth surfaces with some gentle variations. One of the reasons why smooth surfaces are the point of discussion here is that if the surface is too rough then there would be a variation local variation of the electric field and in our approach that we have used of the algorithm we have developed really that variation for electric field is not accommodated. We still assume the electric field to be constant depending on the function of the inter-electrode gap and the lambda the way lambda is defined is really for a constant field case where we assume that the lines of forces are fully parallel to one another the field is homogeneous all through the 2 electrodes the workpiece and tool so on so forth.

If the field is locally varying which is the case when there are surface topologies of small size which would create coiling of the lines of forces in that case, we cannot use the simple you know homogeneous electric field solution to define the functional mapping between the workpiece and tool. So, there would be a complication which is imposed because of the roughness of both the surfaces if it is above a certain value. So, for more complex shapes and surfaces particularly involving sharp curves this is something that you have to be look out on and sudden changes. The first thing that we really need to establish is a solution for the electric field itself. So, you should have a solution considering all the sharp corners of the surface topology and all the coiling of the lines of forces and that relationship of field when it so would exist would be automatically translated to find out the lambda value and that way the equilibrium gap ge can be calculated as lambda by f.

So, it would be a more accurate assumption to incorporate into the function mapping strategy. So, when the closed form expression for workpiece surface is not available one option could be that you divide the surfaces into small straight or curved segments of known geometry and then within this local domain if you assume the field to be constant then you can still be able to translate some of these equations in for mapping between the tool and the workpiece. So, instead of the strategy followed earlier which was about just having a single curvature to define the whole surface we would be able to split up the surface into various parts and I think I have illustrated this before that CAD package can really these days convert the whole surface in terms of fits in terms of various parametric or non-parametric curves and segments or planes and so the whole surface can be localized to a local domain and then each domains functional map on the tool surface can be estimated that way you can assume that you are avoiding the corners or you do not need a closed form solution of the electric field you can assume for that local small area the electric field is homogeneous. So, these are some of the important points to remember when you do function mapping. So, the other aspect I would like to really illustrate for the ECM process is the design for electrolyte flow.

So, 1 aspect we have already discussed is how the velocity and pressure could be calculated from before. The other very important method or the other very important part of the layout that we have to plan is how you flow in the electrolyte to begin with. So, for example, in this particular figure here there is a concentric channel which is available on the tool electrode, and this is having an option that the electrolyte can be pumped in, and you can see that because this gap is very small the curvature here is smooth. So, it makes the electrolyte flow in streamline shapes. So, typically these are very high these are very small gaps meaning thereby that sometimes the Reynolds number is very low because it is dominated by the D effective or the effective diameter and its micro scale phenomena.

So, almost always sometimes the flows are laminar or creepy in such gaps. So, therefore, what we need to ensure as a design engineer is that the sufficient electrolyte flow should be there between workpiece and tool and of course, that is because it needs to carry away the heat and the products of machining. Flow is needed for that purpose in any case as we have seen before, and you can also have an assistance to the whole machining process. So, you can have suitability in the surface finish that you obtain, or you know at a certain rate you are trying to produce the machining, or you are intending for certain yield of machining which is defined by this feed rate. So, even for that the amount of heat carrying away carried away is very critical.

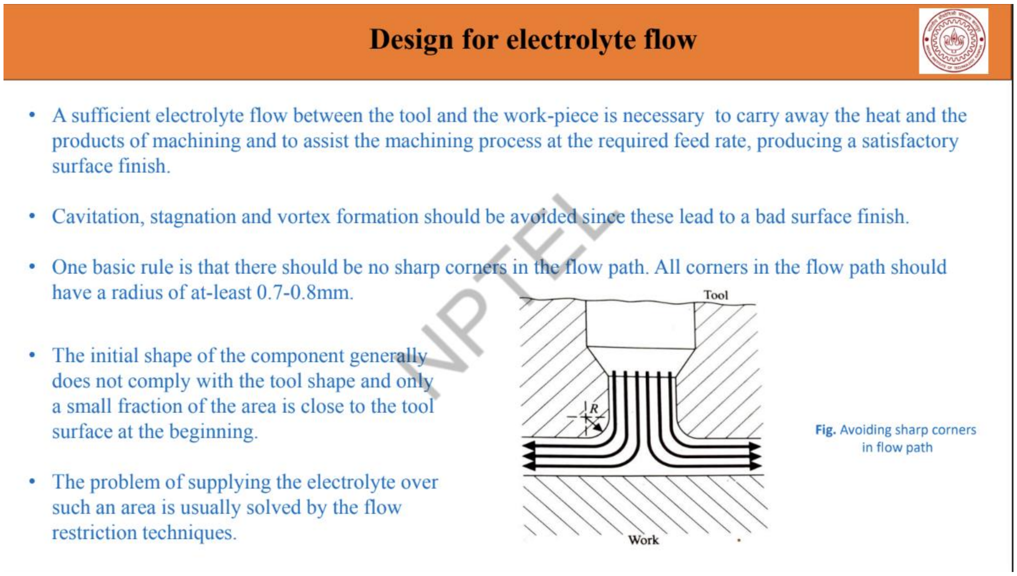
But however, when you are talking about the flow of electrolyte particularly past the surface which it is machining there is of course, problems additional problems that the flow impose 1 is cavitation, stagnation, and vortex formation. So, cavitation happens because of bubbles as you know that this electrochemical machining is all about the carrying away of the debris material as precipitate. There is a and there are certain gases which are sometimes produced in the process there is always a scope for bubbles of micron size which may grow up to some macro size between the tool and the workpiece. So, when that bubbles happen there is a pressure difference because of which some effect can be felt back on the machining rates because of this cavitation. So, the electrolyte moving although it carries the bubble away very fast, but cavitation is a major problem which would come that bubble formation and the influence on the material removal rate because of the bubble formation.

You have seen that in USM case this cavitation happens because of the vibrating tool head at a very high frequency. So, the fluid can no longer follow that tool head and there are thousands and thousands of bubbles which are created because of that because the air typically bleeds out and fulfills the gap done by that vibrating tool head. In the ECM case, the same bubble is generated electrochemically by the system. So, then there can be a possibility of stagnation of the flows. So, there are may be certain it is a creepy flow it is a laminar flow.

So, if supposing there are certain nooks and corners in the workpiece where sometimes because of extremely low let us say discharge rate the perfect streamlining happens. So, supposing there is a surface like this that you are trying to machine with this tool and this tool is shaped in this particular manner with the electrolyte flow across the centre of the tool concentrically. So, if this shapes are perfectly streamlined there may be a case that the fluid molecules go into this local region and there is some rotation or vorticity or vortex formation which happens here and although the remaining part of the flow moves smoothly this local flow remains on 1 place. For example, let us just blow it up and see what happens. Let us say this is the laminarity of the flow at this particular place and there is a big gap here.

So, what would happen is if the flow goes inside the flow would start to rotate in this particular region without being affected even though the up the flow which is on the top of it is flowing in a streamlined and nice manner. So, these are the formation of local vortices of whirlpools. This can be dangerous to the ECM process because number 1 the local conductivity here is really a function of the amount of debris which is coming into this so-called local whirlpool. We can assume that the debris gets confined here in this particular zone you know it does not get moved ahead the remaining debris which is generated from let us say for example, this surface or the other surfaces here would get carried away, but this local debris formulation here does not go ahead anymore. So, there is a change in conductivity, there is a change in machining rate, there is a change in so many parameters which are associated with this vortex formation.

So, we should by and large avoid by designing a flow in a manner so that these vortices do not exist as such. So, as low corners as low as possible such corners or crevices should be kept in designing the system. So, stagnation and vortex formation are a major problem while considering the electrolyte flow. So, 1 basic rule that is followed that is that there should not be any sharp corners in the flow path. All corners in the flow path should have a radius of at least about 700 to 800 microns.



Design for electrolyte flow

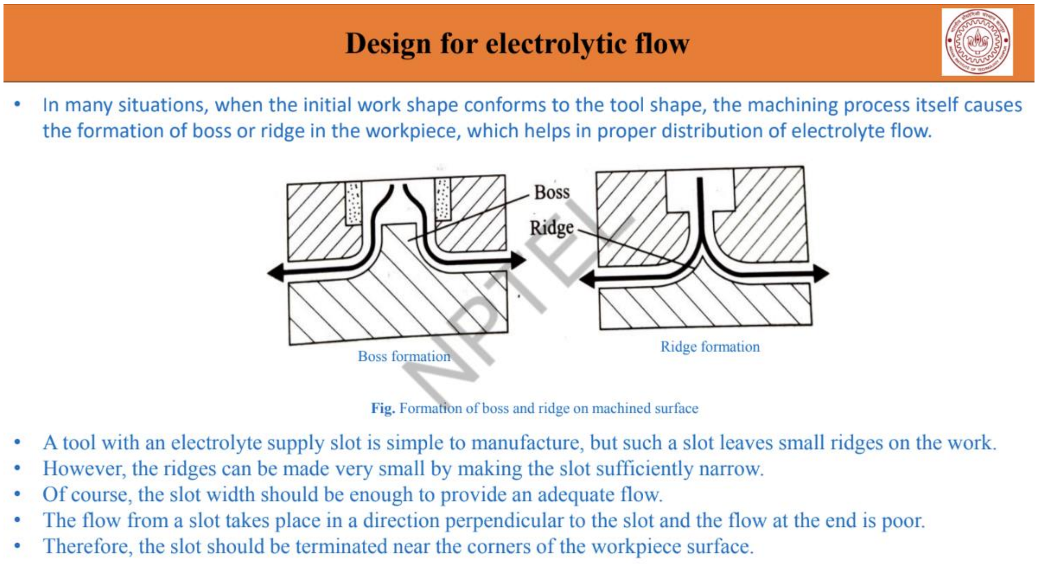
- A sufficient electrolyte flow between the tool and the work-piece is necessary to carry away the heat and the products of machining and to assist the machining process at the required feed rate, producing a satisfactory surface finish.
- Cavitation, stagnation and vortex formation should be avoided since these lead to a bad surface finish.
- One basic rule is that there should be no sharp corners in the flow path. All corners in the flow path should have a radius of at-least 0.7-0.8mm.
- The initial shape of the component generally does not comply with the tool shape and only a small fraction of the area is close to the tool surface at the beginning.
- The problem of supplying the electrolyte over such an area is usually solved by the flow restriction techniques.

Fig. Avoiding sharp corners in flow path

For example, you can see there is a chamfering here at the corner just for introducing this concept of sort of laminarity of the flow which is guided from this corner. So, the initial shape of the component generally does not comply with the tool shape and only a small fraction of the area is close to the tool surface at the beginning and that results in another very interesting problem where you have to actually restrict the flow you know. So, you are going more towards stagnation there, but then there is a reason why we do that. So, in such a situation where the tool in its first approach to the workpiece is covering very small amount of the workpiece area you have to somehow ensure that the flow is guided throughout the inter-electrode gap. So, that machining can start at some point of time once the electric field is good enough for the material removal to take place.

So, you have the concept of flow restrictors which you put in such a situation and just to ensure that the supply of the electrolyte is properly guaranteed over the whole workpiece surface. So, you artificially restrict the flows by creating some dam-like structures. So, that it can go past the whole surface and cover the whole surface. So, 1 issue about electrochemical machining is that you want to have the electrolyte spread out to over the whole area of machining and the other issue is how to get the field to be of substantial value. So, that dissolution can start taking place.

So, this is a problem which would you would hit upon when you are talking about flow design that sometimes the areas are not fully covered because the tool shape initial initially at the beginning of the machining may not be at all uniform or uneven with respect to the workpiece shape. So, there is a possibility of a lot of workpiece area remaining as such uncovered. So, that is another issue you have to take care of for while doing flow designing. So, in many situations for example, when initial work shape confirms to the tool shape. For example, in this particular case, you see that this is the tool and there is a boss on this workpiece which has somehow come into the path of the electrolyte flow.



Design for electrolytic flow

- In many situations, when the initial work shape conforms to the tool shape, the machining process itself causes the formation of boss or ridge in the workpiece, which helps in proper distribution of electrolyte flow.

Fig. Formation of boss and ridge on machined surface

- A tool with an electrolyte supply slot is simple to manufacture, but such a slot leaves small ridges on the work.
- However, the ridges can be made very small by making the slot sufficiently narrow.
- Of course, the slot width should be enough to provide an adequate flow.
- The flow from a slot takes place in a direction perpendicular to the slot and the flow at the end is poor.
- Therefore, the slot should be terminated near the corners of the workpiece surface.

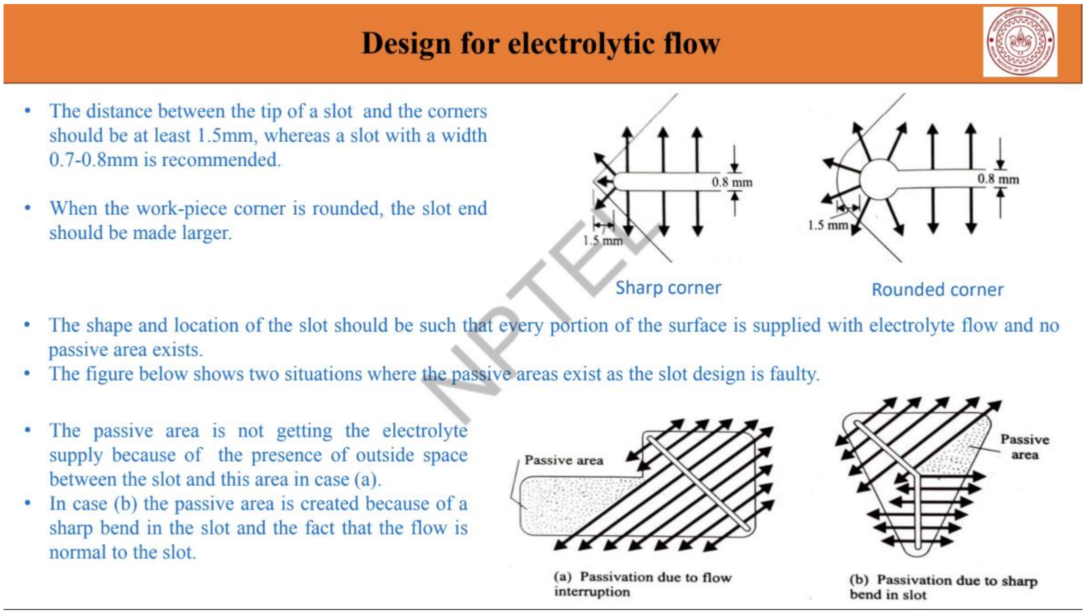
So, there is a small, chamfered corner of this tool and there is a concentric coaxial channel which is available for the electrolyte flow and the boss has somehow the boss on the surface which was existing from before has somehow sort of come in alignment with this coaxial fluid path which has been artificially made in the tool surface. So, what will it result in? So, if such a ridge or a boss comes in the path of the flow the first obvious reaction that a designer would have is to somehow remove it or make it non-aligned. Otherwise, if the flow keeps on continuing here the boss shape would remain because there is no electric field which is actually trying to remove or dissolve away this boss because the electric field happens between the tool and the workpiece here and this zone is far away from the electric field. So, you will have to design the flow in a manner. So, that these problems like existence of such boss or ridges may not hamper the overall strategy of machining that you are following for developing the whole workpiece surface.

So, a tool with an electrolyte supply slot is pretty simple to manufacture, but there is a downside that these leaf ridges or bosses on the workpiece when you talk about such concentrically you know such concentric tooling’s with flows which are coming axially out of the tool surface itself. So, 1 option can be that the ridges can be made very small by making the slot sufficiently narrow.

So, instead of doing this whole width here w you go for a much narrower slot that is let us say w dash, w dash is much smaller in comparison to w. So, that would ensure that the ridge or the boss has minimum size possible, but then the fall of having a very narrow slot is that sometimes the flow may not be enough. So, that the whole area on this other part of the workpiece may be covered with the flow.

So, the slot width should be designed with an idea of how much it would leave in terms of boss or ridges on the surface and also with an idea of how much electrolyte really is needed to be dispensed per unit time. So, that the whole area of the workpiece surface may be covered. So, the flow typically from a slot takes place in a direction perpendicular to the slot and the flow at the end is poor. So, velocity of the flow is highest here where it is emanating out and the velocity here is comparatively lesser because there is frictional effect between this point and this point. So, that is another issue that the flow is different in terms of velocity as it emanates or as it goes away from the workpiece zone.

Therefore, the slot should be terminated near the corners of the workpiece. So, that there is always a possibility of a dam formation as if the fluid is going all the way up to the corner and then emanating out between the corner and the tooling as can be illustrated here. So, you can see these are these flow-restricted dams which I have been talking about. So, that the flow of the electrolyte may ooze out from these corners. Thus, the question of stagnation because of low velocity at the corners would be avoided number 1 because there is a continuous supply and there is a continuous sort of fluid bed which is permanently present on the surface of the workpiece.



Design for electrolytic flow

- The distance between the tip of a slot and the corners should be at least 1.5mm, whereas a slot with a width 0.7-0.8mm is recommended.
- When the work-piece corner is rounded, the slot end should be made larger.

- The shape and location of the slot should be such that every portion of the surface is supplied with electrolyte flow and no passive area exists.
- The figure below shows two situations where the passive areas exist as the slot design is faulty.

- The passive area is not getting the electrolyte supply because of the presence of outside space between the slot and this area in case (a).
- In case (b) the passive area is created because of a sharp bend in the slot and the fact that the flow is normal to the slot.

(a) Passivation due to flow interruption

(b) Passivation due to sharp bend in slot

So, some of these strategies can be intelligently designed for such a system. When you are designing the tools for with sharp corners for ECM process you have to follow some thumb rules. For example, the distance between the tip of a slot and the corner. So, we are talking about this distance from this tip to the corner and there should be at least 1.5 mm for obvious reasons that there has to be sufficient.

So, there may be some electrochemical machining of the tooling itself although the tooling is chosen in a manner so that it does not happen, but then 1 has to ensure that the slot does not go all the way to the site of the tool face and therefore, there has to be a gap. And also, the slot with the width of typically width of 700 to 800 micron is recommended as I have earlier told also. And when the workpiece corner is rounded the slot end should be made larger. For example, you can see a particular case here this is a rounded corner, and you are deliberately making the slot end larger because you want the flow to reach in all the directions. If the slot were narrow here may be the flow would not have been able to reach sufficiently the wholly fully chamfered corner.

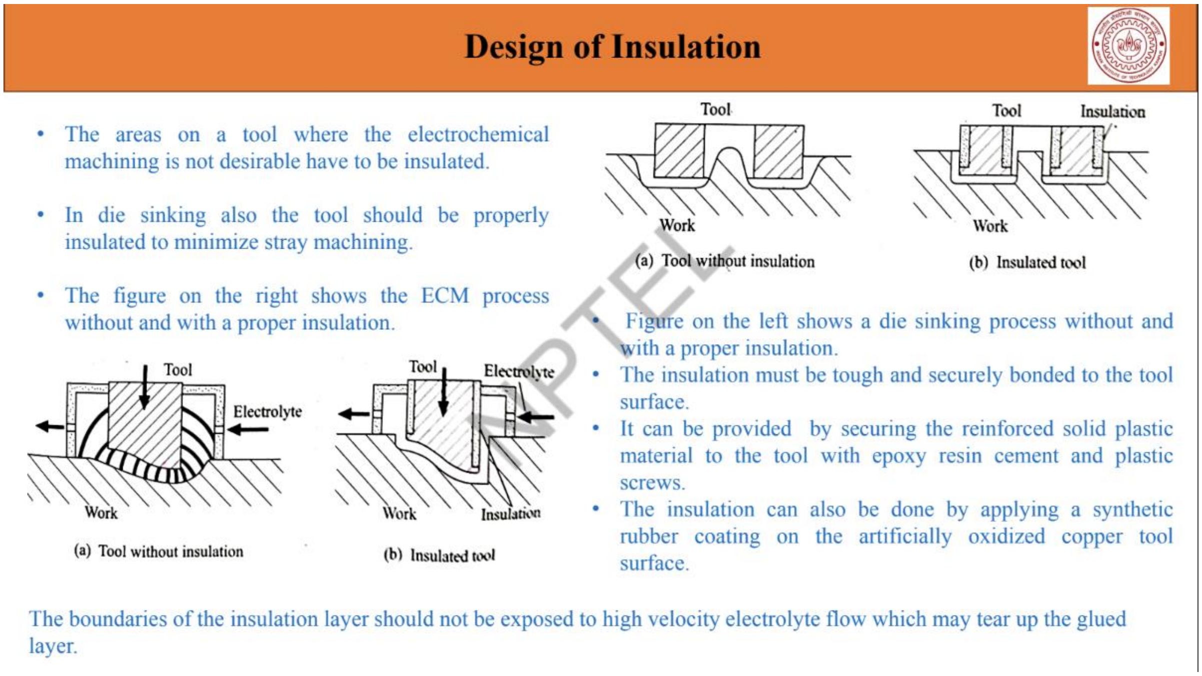
So, you have to ensure that the flow reaches. So, maybe some shape equivalence between the chamfering here and the corner of the slot is needed. And the shape and location of the slot should be such that every portion of the surface is supplied and there is no passive area. For example, see this very nice problem here. So, you have a straight slot cut at a particular angle on this particular tool and you can see that the electrolyte although it emanates from the slot uniformly is not able to spread it to the whole area.

So, this area remains passive. Similarly, in this case, it remains passive here. So, a better design of such electrode would be, for example, to change the slot into a curvature with a certain curvature. So, that you can guide the flows. So, in this particular case, there may be a flow coming out here, there may be a flow coming in this direction, there may be a flow coming in this direction is already illustrated, this direction perpendicular to the slot is already illustrated. And so, the idea is that the curvature of the slot has been designed in a manner.

So, that the full area can be supplied with the electrolyte. Same is the case here. You have just taken that slot which was earlier a straight edge or a combination of straight edge here and have just introduced a small curvature. So, when you introduce the curvature, you see that there is a coverage of the electrolyte assuming that the electrolyte emanates perpendicularly to the slot and it goes and covers the whole surface. So, some of these strategies need to be developed intelligently by looking at the workpiece shape that you really want to machine.

And it is a job of a designer to also while designing the tool consider that the flow of the electrolyte should be uniform, and it should at least cover all the surface that 1 is trying to machine. So, we have talked about flow restrictors, we have talked about how the slot shape and size can be changed, what are the thumb rules which are followed particularly for designing slots near corners. If the corner is chamfered what is the thumb rule followed? All these aspects of designing of how the flow can be emanated out of the tool have been looked upon and these are some practical problems related to ECM just because it is a time-based process that as the electrolyte keeps on circulating the debris would be generated and the workpiece would slowly get machined off. So, the other issue which is needed for considering ECM is how to develop good insulation on the tool and there are good number of reasons for developing insulation.

For example, let us say this figure here considers an uninsulated a completely non-insulated tool. So, there would be ECM carried out between the tool and the workpiece in this direction which is what we need or what is intended for, but then also there would be ECM carried out between the sides of the tool and the workpiece. Therefore, as you can see here that if we were intending for a some size of the hole that we were trying to drill with ECM may be the hole has gotten extended



Design of Insulation

- The areas on a tool where the electrochemical machining is not desirable have to be insulated.
- In die sinking also the tool should be properly insulated to minimize stray machining.
- The figure on the right shows the ECM process without and with a proper insulation.

(a) Tool without insulation

(b) Insulated tool

- Figure on the left shows a die sinking process without and with a proper insulation.
- The insulation must be tough and securely bonded to the tool surface.
- It can be provided by securing the reinforced solid plastic material to the tool with epoxy resin cement and plastic screws.
- The insulation can also be done by applying a synthetic rubber coating on the artificially oxidized copper tool surface.

(a) Tool without insulation

(b) Insulated tool

The boundaries of the insulation layer should not be exposed to high velocity electrolyte flow which may tear up the glued layer.

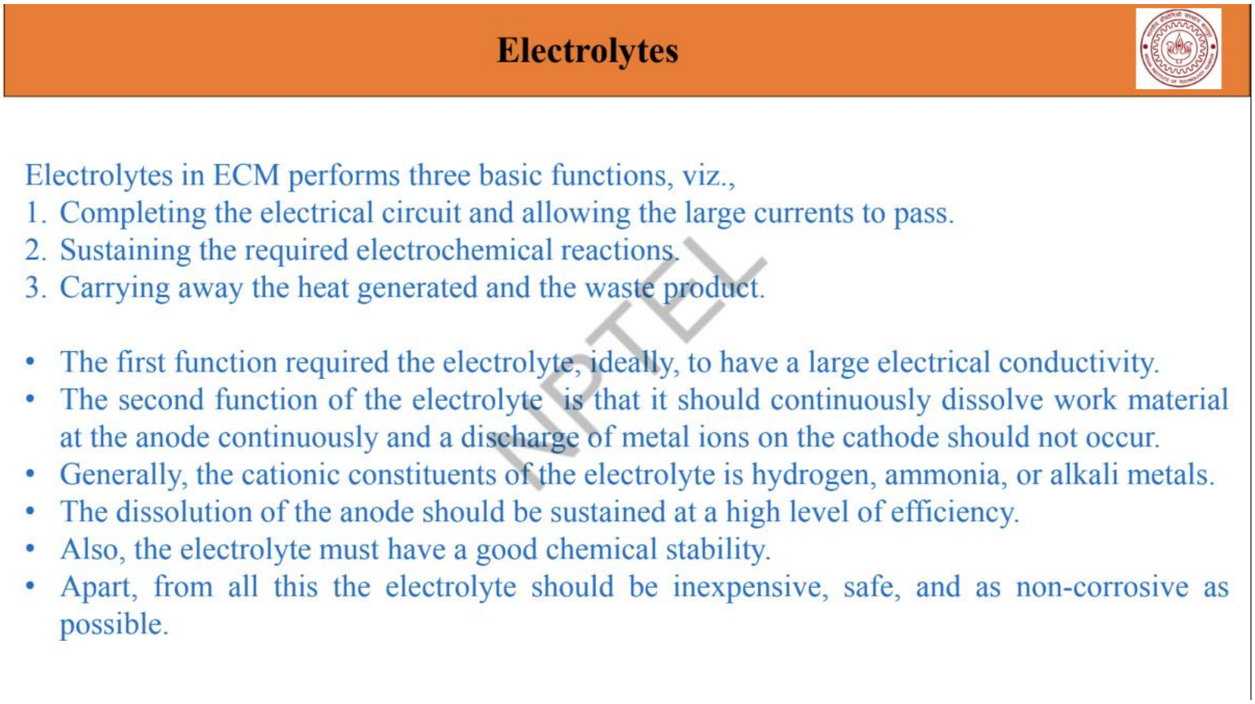
and there is a lateral cut thus ensuring that the hole is broader in size and so, 1 way to prevent this from happening is to somehow stop the field. You cannot stop the flow of the electrolyte because it goes and covers all the surface, but you somehow stop the field to go and take out the material at the corners by designing this insulation on the tool surface which would typically mean that the current now, the current density vector which is responsible for all the electrochemical movement is only confined to this portion of the surface. The remaining portion is insulated now and so, there is no field loss as such from this portion of the surface onto the other portion of the workpiece here and that ensures that the size of the hole that was intended while doing let us say the drilling operation with ECM is met.

So, another example of insulation can be seen here. In fact, look at the difference that it creates between the shape here and here just by adding these 2 insulations on the electrodes. So, because it is a die sinking process and it goes into the, this is the case where the tool is actually physically going into the workpiece thus trying to make a matching of you know the topology of the tool surface itself onto the workpiece surface. It is very important that we get rid of all those stray effects which would happen between the walls of the tool which is away from the surface of the tool onto the workpiece. So, insulation can be done by securing reinforced or solid plastic material to the tool with epoxy resin cement and sometimes plastic screws. In fact, 1 has to be careful the moment the term insulation or the moment the term insulated pads come into picture they have to be very well pasted onto the surface of the tool.

A little bit of gap between the insulation as such and the tool surface would result in number 1 incomplete finishing because bosses or ridges may formulate because of that gap on the surface. At the same time, it can also take away the insulation with time because water because there is a continuous action of the electrochemical action which is going on into whatever portion is uninsulated and leftover of the tool side. So, therefore, typically you have to secure the insulation very firmly onto the sides of the tool. Also, you can actually insulate by applying synthetic rubber coating on the artificially oxidized tool surface. This is a very prominent technique, particularly for copper tools.

So, you can give a coating by masking the tool appropriately and giving coating so that, later on when you remove the mask the portions which are beneath the mask would be not coated. And so, you have a very clearly demarcated insulated and non-insulated region on the tool surface. The boundaries of the insulation layer should not be exposed to high velocity of electrolyte flow because, sometimes they tear up the glued layers as I already told you. And this automatically by virtue of the fact that insulation is needed mostly towards the end. In designs where the tool has the concentric is the capability of delivering the electrolyte coaxially.

This is really not a major issue because the velocity seems tends to drop from the centre to the side of the particular tool. But, in cases where electrolytes are flown like in this particular case electrolytes are flown from 1 side to other 1 needs to ensure that the insulation is properly glued onto the workpiece surface. Let us now look at the other part that is electrolytes which you need to design for ECM systems. So, let us just first find out what are the basic functions associated with an electrolyte. So, 1 it allows the completion of the electrical circuit between the tool and the workpiece.



Electrolytes

Electrolytes in ECM performs three basic functions, viz.,

1. Completing the electrical circuit and allowing the large currents to pass.
2. Sustaining the required electrochemical reactions.
3. Carrying away the heat generated and the waste product.

- The first function required the electrolyte, ideally, to have a large electrical conductivity.
- The second function of the electrolyte is that it should continuously dissolve work material at the anode continuously and a discharge of metal ions on the cathode should not occur.
- Generally, the cationic constituents of the electrolyte is hydrogen, ammonia, or alkali metals.
- The dissolution of the anode should be sustained at a high level of efficiency.
- Also, the electrolyte must have a good chemical stability.
- Apart, from all this the electrolyte should be inexpensive, safe, and as non-corrosive as possible.

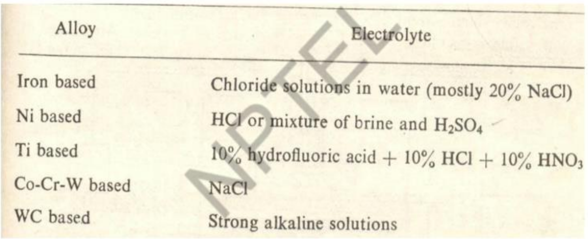
So, this is the only conducting means between the tool and the workpiece and it should allow flow of large currents. So, that those current density is typically account for the material transport from the workpiece surface onto the electrolyte itself. Also, the electrolyte should have ways and means to sustain the required electrochemical reaction which is going on. And it should be a good carriage for the heat which is generated by the electrical power that is pumped on from the electrode the tool electrode onto the workpiece and also to carry away the waste products in turn. So, it should be able to somehow locally carry away whatever debris is generated, and it should also be able to carry out the heat that is pumped in from the tool side to the workpiece side by the I square R power that it is delivering on to the electrolyte.

So, what are the requirements? So, the first function should require that the electrolyte be of large electrical conductivity and the second function should require that it should continuously dissolve work material at the anode. So, it should sustain the electrochemical reaction at the anode, anode is the workpiece in this particular case. And it should discharge, or it should discharge the metal ions that come in by virtue of some chemical reactions thus leaving no residue on the tool surface. So, whatever ions are emanating from the workpiece surface should be able to get chemically dissolved within the electrolyte system. So, electrolyte is a sort of barrier between the material that gets transported from the workpiece and the tool.

Otherwise, there would be a coating on the tool although you cannot prevent 100 per cent coating there may be instances where there is some formulation of oxide or something on the tool with time. But then 1 has to ensure that the choice of electrolyte be in a way that whatever comes out of the workpiece gets precipitated and does not get deposited onto the other electrode. So, the dissolution of the anode should be sustained at a high level of efficiency by the electrolyte and there are some other cationic constituents of the electrolyte like hydrogen ammonia or alkali metals which should be part of the regular process of the electrolyte. So, whatever the tool generates is either a gas or something which again creates a reaction with the electrolyte itself.

The electrolyte, of course, must have good chemical stability. So, it should not degrade with time, and it should be as inexpensive and safe environmentally safe as possible because it should not create any toxic vapours or fumes for the operator to get exposed. So, in a nutshell, good conductivity of the electrolyte the ability to dissolve away the workpiece by precipitating whatever is coming out or whatever cationic reactions are happening at the tool side, or the cathode side is supported by emanation of a gas like hydrogen or ammonia something like that. And the very fact that it should be of a highly sustained nature, or it should as far as the electrochemical operation of the workpiece goes. So, these are all necessarily included for the choice of electrolytes. Let us look at some of the systems which are existing typically for some conventionally used alloys of engineering importance.

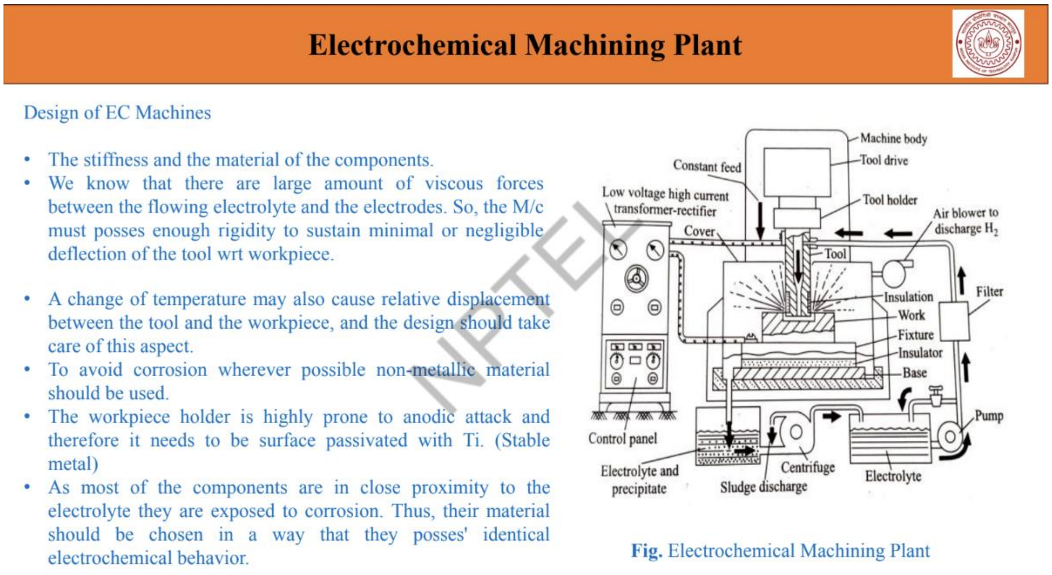
Types of Electrolytes



Alloy	Electrolyte
Iron based	Chloride solutions in water (mostly 20% NaCl)
Ni based	HCl or mixture of brine and H_2SO_4
Ti based	10% hydrofluoric acid + 10% HCl + 10% HNO_3
Co-Cr-W based	NaCl
WC based	Strong alkaline solutions

So, for iron-based systems, the electrolyte that is normally used as chlorine solutions in water you know brine solution comparing or consisting of kitchen salt in water 20 per cent concentration is typically used for iron-based workpieces for electrochemical machining. For nickel-based samples, you use either hydrochloric acid or mixture of again salt water and H2SO4. For titanium-based constituents can use a combination of 10 percent hydrofluoric acid, 10 percent HCl hydrochloric acid and then 10 percent nitric acid. For a cobalt chromium tungsten-based system people have tried again salt solutions and for tungsten carbide which is very often used for tooling applications strong alkaline solutions. So, these are typically some of the electrolytes which are used for the ECM machining process.

We now look at the ECM plant the way that the electrolyte is circulated, and all this machining happens. So, this is a very nice schematic of what all goes into an ECM system. So, you should have a electrolyte pumping mechanism this is a electrolyte storage and basically have a pumping mechanism and a discharge mechanism. So, normal operation you can keep this valve on. So, that whatever pumps out goes in back and if it is switched off then the electrolyte can get circulated into the system.



Electrochemical Machining Plant

Design of EC Machines

- The stiffness and the material of the components.
- We know that there are large amount of viscous forces between the flowing electrolyte and the electrodes. So, the M/c must posses enough rigidity to sustain minimal or negligible deflection of the tool wrt workpiece.
- A change of temperature may also cause relative displacement between the tool and the workpiece, and the design should take care of this aspect.
- To avoid corrosion wherever possible non-metallic material should be used.
- The workpiece holder is highly prone to anodic attack and therefore it needs to be surface passivated with Ti. (Stable metal)
- As most of the components are in close proximity to the electrolyte they are exposed to corrosion. Thus, their material should be chosen in a way that they posses' identical electrochemical behavior.

Fig. Electrochemical Machining Plant

So, the electrolyte goes through a filter this right here is the filter and it is injected into the tool. This is a coaxial tool where you can see the electrolyte coming out of the tool in a very small slot at the end of the tool here right here. And then the electrolyte flows on both directions into over the workpiece surface. As such it discharges whatever hydrogen or gases come out or emanate of the tool side there should be a capability of blowing them out. So, this environment being closed whatever hydrogen is generated or ammonia is generated as a subprocess of the tool side.

So, where all the ion transport would happen because of the generation of the gas that gas can be discharged. So, there should be a discharge port for the byproducts of the chemical reaction coming out. And then, of course, there can be a way that you can recirculate the electrolyte. So, you can basically either precipitate and do a sludge discharging. So, that whatever electrolyte you can recover here can be recirculated back although it is really not a very good idea to do that.

And then of course, you should have a very strong stage which should have enough rigidity to sustain the deflection of the tool as I already have illustrated before. This zone here of flow is so small that the viscous forces provided by the flowing electrolyte sometimes gives huge amount of pressures and force is basically pressure times area. So, whatever interfacial area is there on the tool surface that kind of gets influenced by the force that it feels. And so, the tool is not rigid enough it is amenable to wobbling sometimes, particularly when you are feeding and that may create a local zone which is much more in its dimensions than a intended dimensions of that zone. So, therefore, 1 has to be careful about the holder the tool holder it should be of sufficient amount of rigidity.

And a change of temperature may also cause relative displacement and somehow this design should be able to take care of this aspect also. So, if need be, sometimes the tool needs to be cooled. So, that there is no tool needs to be cooled. So, that the relative displacement between the tool and the workpiece do not happen because of temperature gradients or thermal gradients. Also to avoid corrosion wherever possible non-metallic material should be used which is not amenable to the electrochemical machining process as such.

The workpiece holder is very much prone to anodic attack therefore, it needs to be surface passivated sometimes with titanium or a stable any other stable metal. As most of the components are in close proximity to the electrolyte even, they are exposed to corrosion it is a electrochemical process. So, wherever there is a electrolyte and wherever there is a field there is corrosion. So, the material should be chosen in a manner.

So, that identical electrochemical behaviour comes of all these materials. So, in a nutshell, the job of a designer of a electrochemical plant is really to look at the machining system from an overall standpoint. So, the main idea is that whatever electrochemical changes are happening should be limited to either the tool or the workpiece. And that also on a very minuscule basis on the tool side. The remaining components which are participating in this electrochemical machining process and is amenable to attack because of the reach of the coolant or reach of the field they should be passivated in a manner.

So, that they do not influence the electrochemical process of machining going on. So, that is in a nutshell what the electrochemical machining unit should look like. We will talk about some other aspects of this electrochemical machining in our next lecture. And we will try to cover some additional processes like electro-stream drilling or electrochemical grinding or even electrochemical drilling. So, ECG or ECD, ESD as they are commonly known as and we will try to then wrap of by saying or by looking at the applications that such systems may have to microsystems engineering. Thank you.