Micro Fabrication with Advanced Manufacturing Techniques
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Lecture - 16
Microsystems Fabrication by Advanced Manufacturing process

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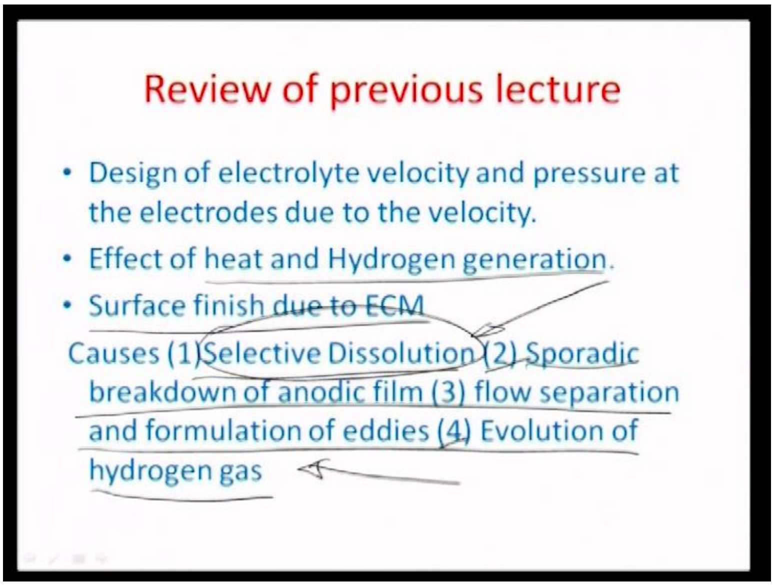

Hello and welcome back to this micro system fabrication by advanced manufacturing process lecture 16. A brief review of the previous lecture what we have tried to do last time was to design the electrolyte velocity and pressure between electrodes due to during and ECM operation. And we saw that the velocity is actually a limited by the fact the amount of heat that is translated by the electrical power coming into 2 electrolyte is carried away, assuming that there is no conductance across the tool work piece surface. And the velocity should be designed in a manner, so that the overall temperature of the electrolyte does not cross the boiling point.

Also what is important is that velocity is also limited by the pressure scale where the pressure comes to the 2 factor. So, 1 is the initial component which is relatively a lower term particularly because of creepy flows or low remold number flows, which are executed in the small equilibrium gap, that is an question. And so therefore, the pressure component given by the surface forces, the whisk is forces have to be matched with the ultimately the trust of the material on 1 side.

So, that is what limits the velocity and design velocity of the electro light. So, what documents the velocity is the fact that the temperature should not go below the boiling point and what limits the velocity is the fact that, is the fact that the pressure which is generated because of the whisker effect of this velocity should not go above the ultimate truss of the material.

We also sort of tried to investigate the various effect of the heat and hydrogen generation on ECM process between the electrodes on the electrolyte. And we were looking at some of the causes of surface finish due to ECM operation including selective dissolution, sporadic breakdown of anodic film, flow separation formulation of eddies, evolution of hydrogen gas so on and so forth.

So, we had already seen how 2 phases an analogy a and b with different dissolution potentials would have a self roughening effect as a post to the general self leveling effect of an ECM process. Just because of the fact that the potential of 1 phase will be slightly higher over the potential of the other phase.

So, it was a very interesting case, that we analyze were roughness automatically get generated because of difference in the dissolution potential of the 2 phases. The other a fact is about you know this sporadic breakdown of anodic film which we will just about see today. And all this different causes varying from 2 to 4 will try to evaluate today after going through the brief recap of the dissolution potential.

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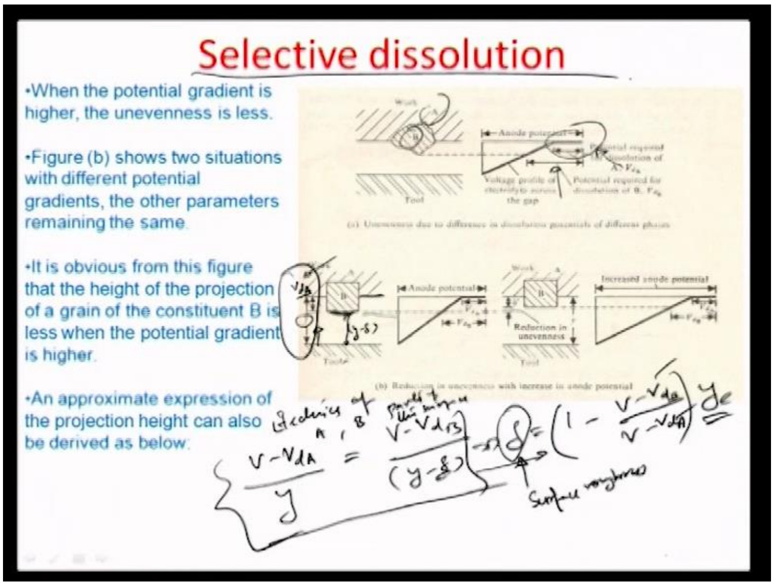

So, here you can set that are 2 phase b and where there is a difference in the potential dissolution potential VdA dissolution potential of a is lower in comparison to VdA. Therefore, there is a self roughening were the b phase only get dissolve when you create this particular plane this is just for the sake of repetition that I am doing. So, if you really compare both the cases …

So, the electric filed which is also proportional to the current density, because electric field times the conductivity becomes the current density. Actually, if you look at this as gap as y in tool on the surface a and the available potential dissolution for a is V a. So, V minus VdA by y is the electric field across this particular gap.

If you consider VdA potential or dissolution potential away and if you contain come that consider that as b then the gap reduces to y minus delta here by, the field becomes equal to v minus VdA by y minus delta. And typically this electric field should be similar to each other because they are with 2 equi potential surfaces when question. There should not be really much variation, at least at the flat phase of this b surface and flat phase of e surface. We are not considering corners here by the fields like automatically cohelant would produce considerably varied the density here.

So, this is how the electric fields of the a part of the surface the b part of the surface is would compare and from this expression we really can get the value for this delta. So, the delta thus can be found out by this expression 1 minus v minus VdB by v minus VdA times of y. This algebraic manipulation from this particular equation here and. So, you can really find out what is the surface roughness. If you knew the dissolution potential of the phase A and B and your aware of the gap when the 2 surfaces an equilibrium. So, this is can be the equilibrium gap. So, that is what selective dissolution mean.

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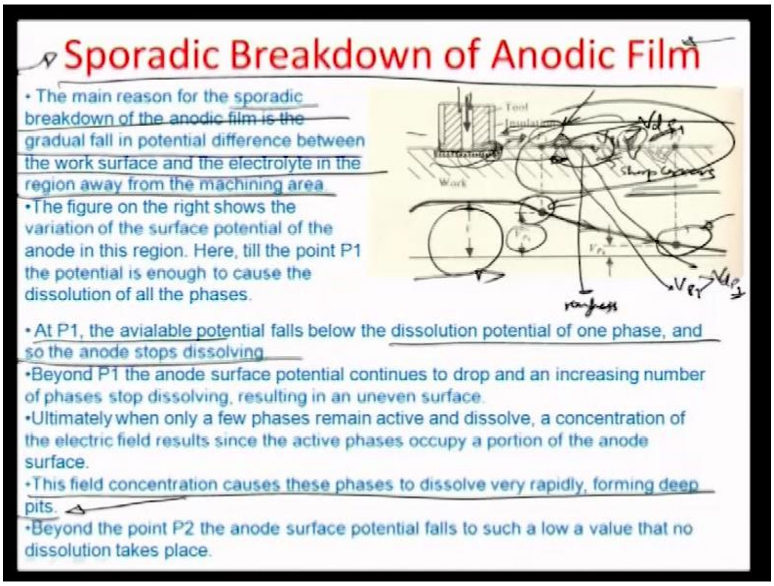

The other very interesting factor which affect the surface roughness is the sporadic breakdown of anodic film let see how it happens. So, the main reason for the sporadic breakdown of the anodic film is the gradual fall in the potential difference is between the work surface and the electrolyte in the region away from the machining area; obviously. Because let say this is the electrode here and there is a certain field which is created in this particular gap, which is represented by this line of forces of fields which is slightly curled around the corners.

It is also reasonable to assume that this field here can extend farther away from the tool surfaces you have, because field is actually goes away from the tool it varies as a or it as a inverse square of distance arch's. So, the filed varies as a square of distance from the electrode onwards towards the remaining part of the surface. But their does exist a field. So, for example, if this is the particular potential function which is valuable to this surface it slowly goes down as the distance increases the square of r.

But, there does exit from value here like for example, at p1 it may be Vp1 at the point p2 it may be Vp2 so on so forth. So, there are some finitely existing values of the fields which escape, even though the tool is placed at some distance away from the surface right. This is all covered with electrolyte because naturally the electrolyte flows around this gap and flows over the surface and everywhere else; when it flows into the tool from this entry point here in center.

So, supposing if there is an lie in this particular region and particularly in region p1 there may be a phase where, the potential which is available here is greater than the dissolution potential of that particular phase available at p1. So, there would be selective dissolution at p 1 by; obviously, by the region shown before. And so dissolution potential of 1 phase then sure that only 1 phase comes. So, you can see here the roughness which is created is because maybe one of the phases here in this particular zone nor in this particular zone may be had the valuable potential Vp1 to be greater than their own dissolution potential.

So, you can call it Vd of a phase may be p1 and that came off and because of coming of you have this roughness or surface which results because of that. Obviously, there are corners and bends which are that presented by the selective removal of some of the phases. Its corner would further lead to the coiling and the curling of the fields and so the line density in this point would increase tremendously. And because of that there would be more dissolution which is valuable because of increase line density.

So, the field concentration causes the phases to dissolve very rapidly, further because of selective dissolution and formulation of these corners. So, suddenly this is something which is highly undesirable for an ECM process and this can be 1 main mechanism for introducing surface roughness an in ECM, although the e cm is supposed to be a self leveling and a very smooth operation.

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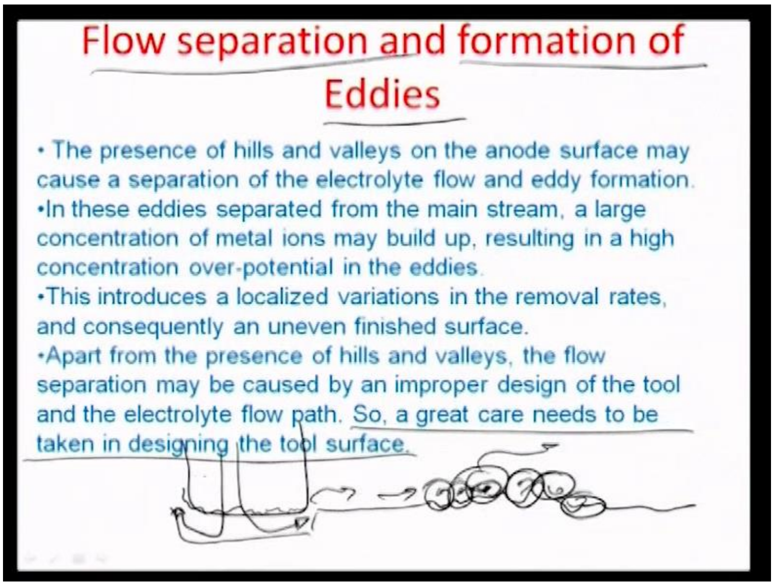

The other important factor which is a responsible for the creation of surface roughness is the formulation of Eddies and separation of the flow. If supposing there is a rough surface which has been created, because of the selective dissolution of the field due to an electric electro chemical tool, it is always proper to assume that there may be a case local circulation. But it will only when the electrolyte is flown in both the directions like this.

So, that electrolyte flows over to the surface and there the cases of local surface circulations; it would exit over such. Meaning thereby, that there are the eddies on which are created close to this corner because of the surface perturbation which is the survey is no longer a plane surface. There are selective dissolution because of which there is a lot of this cornering effect scampering effect which is present at various points here.

So, this local circulations are a cause for debris particles which come out from this zone to keep circulating here without going further. And that may change local conductivity because precipitated are 1 of again the responsible causes for change of the conductivity of the medium electrolyte. And Eddie is a something that you really do not want in ECM the more stream lined operation the ECM would have in terms of electrolyte flow the better it is in terms of surface finish.

But, the more there is localization of flows and Eddies and separation of flow at certain areas. There may be local prohibited worn pool, which are formulated, which have much more conductivity, and therefore more dissolution that may create a pitting effect in some of the local zones.

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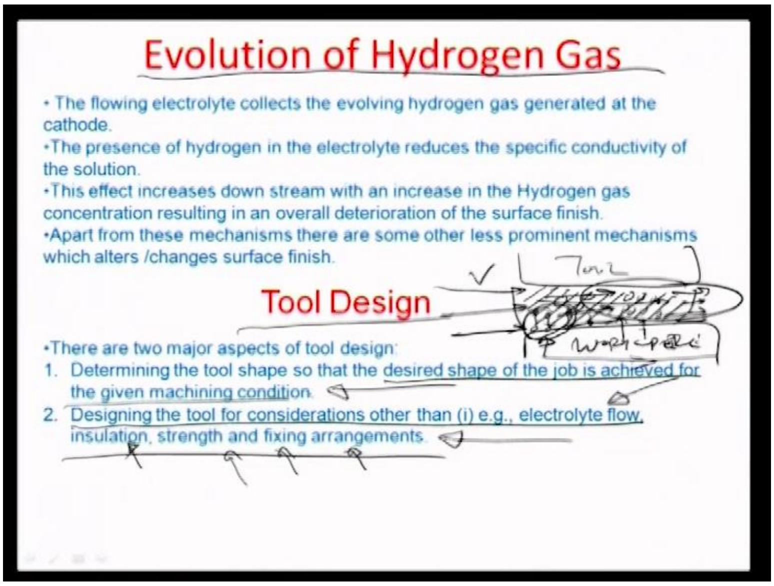

So, great care needs to be design uh to be taken in designing to tool surface particularly. The same thing may happen to the selective dissolution of the tool as well the surface may turn out to be rough with the operations if that is an alloy tool which is used. And 1 needs to very careful about Eddies and flow separations. So, this is another 3rd reasons for the surface roughness finally, as I have already have mentioned before the evolution of hydrogen gas, is pity critical. And if you can consider this tool surface supposing the electrolyte starts flowing from this and into the gap at a certain velocity.

By the time it reaches at the other and here the resolves was a increase in the temperature and let say if hydrogen its bubbles into this electrolyte. The concentration local concentration of hydrogen in the electrolyte increases because of which there is a change in conductivity. And the hydrogen may be concentration may be lesser here, but by the time this goes ahead and the hydrogen get scattered away more and more hydrogen packs off you know to this electrolyte.

So, hydrogen concentration is brittle here there is a density gradient which is created for the gas which is dissolved. And therefore, the conductivity is varied across the length of the work and because of that again there is a tendency of the conductivity to vary and also simultaneously the current density to vary. So, at 1 point were the current density may be more because of a reduced hydrogen, may have slightly greater dissolution grade in comparison to the point where the current tendency use lower.

So, therefore, again this can also result in some kind of roughness were some points may be moved or dissolved in a greater pace in comparison to the other parts. So, there are 2 major aspect when we talk about this e c m 1, of course the tool design and another is the flow design the system of flow you know. And tool design is important because of 2 reasons 1 is that the tool shape so desired is exactly the negative replica of the shape that you are wanting to embed or imprint on to a surface. That is a basic principal of e c m operation.

So, particularly in micro system technology when we are talking about some embedment some small feature which has to be created on the surface, the exact contouring of the tool is very much is very needed. So that the exact negative replica and we produce on the surface of that particular scale. And the other reason is that you know the electrolyte flow that the tool would have would really we creating a lot of effects on the overall material immovable grade. So, therefore, the way that the electrolyte is flown the way that the sides of the tools insulated the strength and fixing arrangement of the insulation on to the tool. They would be a great concern then we want to develop the good ECM process.

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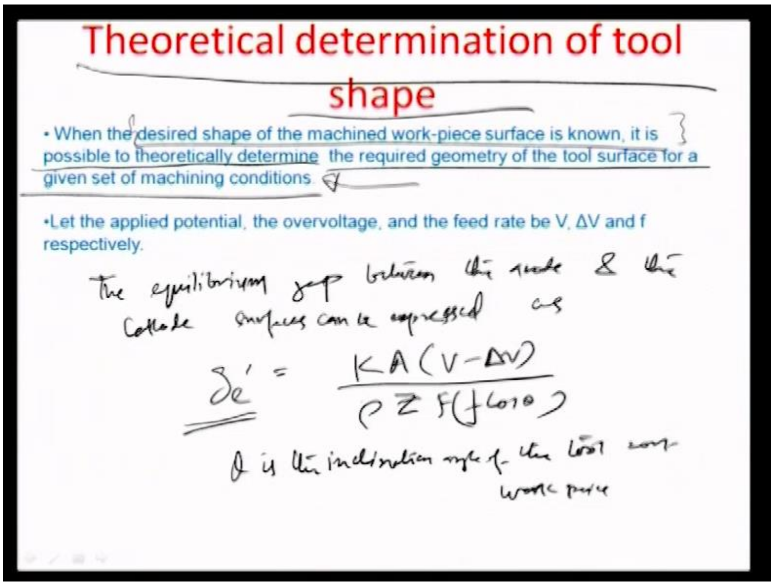

So, we will look at the 1st aspect now that is determining a tool shape so that, the desired shape of the job can be achieve for a micro machining or for a machining condition. And in that respect I would like to sort of propose theory were we want to theoretically determine what is the tool shape based on a certain function, which is ah known to be the final shape of the work-piece that we would like to generate using ECM.

So, on a desired shape of the machine work piece surfaces known and we want to somehow map the surface into a tool surface. And which is possible actually theoretically, I will just show you an approach theoretically determine. So, the required geometry of the tool surface for a given set of machining conditions can be achieved very fast based on that. And the first thing, that we need to know here that the equilibrium gap between the anode and cathode surfaces can be expressed a g dash is equal to the conductivity times over material which is dissolved times of the voltage minus over voltage.

Potential which is valuable for the electro chemical process divided by the density of the material to be remove the lowest material. And some others parameters like the Faraday constraint the ferried supposing, it is going at angle theta. So, if theta is an indication angle of the tool with respect to the work piece and this can be called as f cause theta. So, that is how you find out the equilibrium gap as we have seen before.

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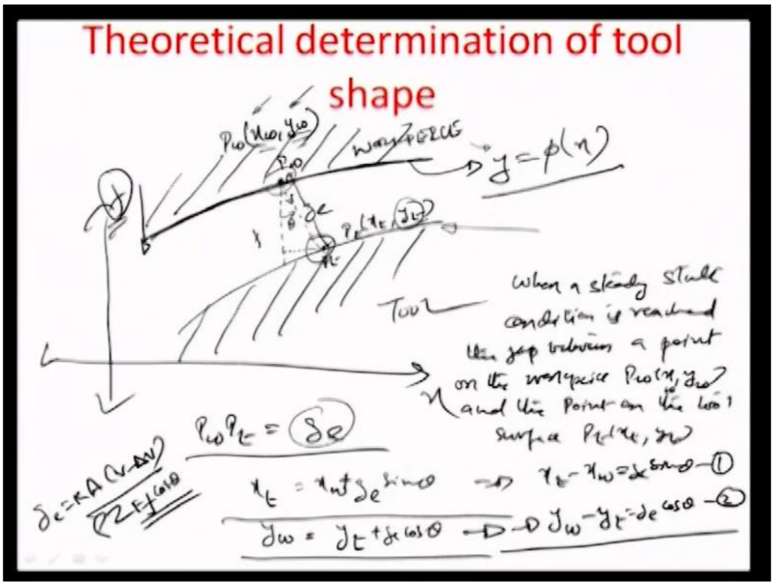

Lets actually now assume a certain random tool surface and work see work piece as represented here. Let us say this is the x y plane and we were talking about a certain shape her of the work piece. Let say this is the shape of work piece which we are a kind of a this shape would result or what would be the final shape would be desirable. So, this is given by the design, design team for the component. And we also are aware this work piece is being fed towards the tool of f and this is automatically the shape of the tool which is generated by the requirement of the work piece surface which is known to you.

So, if we select the you know in the 2 dimensional sense point here on the work piece surface. Let say Pw which is again the function of xw and yw and find to map a corresponding point on this particular surface the tool surface et st yt. We should be able to somehow find out the functional relationship that exist between this point and this point, given the constraints or condition of the e c m process like the feed the direction of the feed so on so forth.

So, the feed as you know is in this direction, meaning there by that if you look at a tangent to this particular point it would assume to how move that an angle theta with respect to the direction of the feed. So, we are already aware of the work piece surface. So, let be define by a function y equal to pie x. So, there is a relationship between this 2 co-ordinate x and y and that is sort of non parametric representation of the surface y pie x. And we want to determine what this 2 mean when it is get translated tool surface to provide the tool shape.

So, when a steady state is condition reached the gap between a point on the work piece, let say this xw yw and point Pw and the point on the tool surface be given by a steady sate equilibrium gap g we have calculated before we know what g. Its function of many things like where the equilibrium gap is a function of many thing a s you know the atomic weight the available voltage which is there, the conductivity. The density of the work piece which material may be iron or copper whatever is being move the machine so on so forth.

So, if you look at the position and relationship n between this co-ordination of x w y w and xt and yt and xt is placed forward its place from the x w by and amount g sin theta. Where g is the gap here between Pw and Pt right and if you compare the position coordinate yw and yt, the y w is forward displaced from the y t and by a gap g cause theta. Meaning thereby, you have 2 equations here xt minus x wwhich is g sin theta that is called a equation 1. And yt minus or yw minus yt which is g cost data qualifications 2.

You already know the value of g, g is actually KAV minus delta V divided by row then f. But we assumed that surface you moving around the line Pw Pt 2 was the tool surface. So, these are very generic form of a surface of multiple certain functional shape to be replicable in terms of the tool surface. So, we are mapping from the work peace surface to the tool surface by using simple mathematics. So, here let us say, if we wanted to just right a within in terms of the new value of g that we had obtains.

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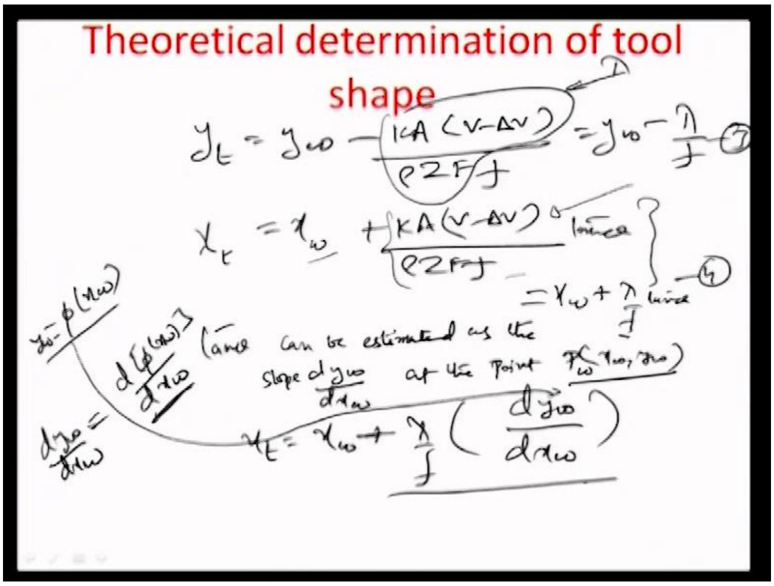

So, yt becomes equal to y w minus KA V minus delta V by row Z f times of f in the which is actually nothing, but yw minus lambda by f. If you should may remember this term here is actually equivalent to the lambda when we with the dynamics of the process. And the xt here can be related to the xw by the term KAV minus delta V divided by, because this was and then the xw was displaced. The xw was displays d backwards from the x t by the terms Z times theta. So, therefore, if you just convert a within a here in terms of lambda you can get x w plus lambda by f time theta.

So, we make this equation 3 and this equation 4. So, you already know that there is a functional relationship between the xw and the yw which exist. So, yw is function 5 of x w in the work piece sight and can be estimated as the slope d yw by d xw at the point Pw xw yw. Where xt equals xw plus lambda by f times of which is d y w by d x w. So, is the work surface geometry is given by this relationship, the d y w by x w actually equals to d 5 xw by d xw.

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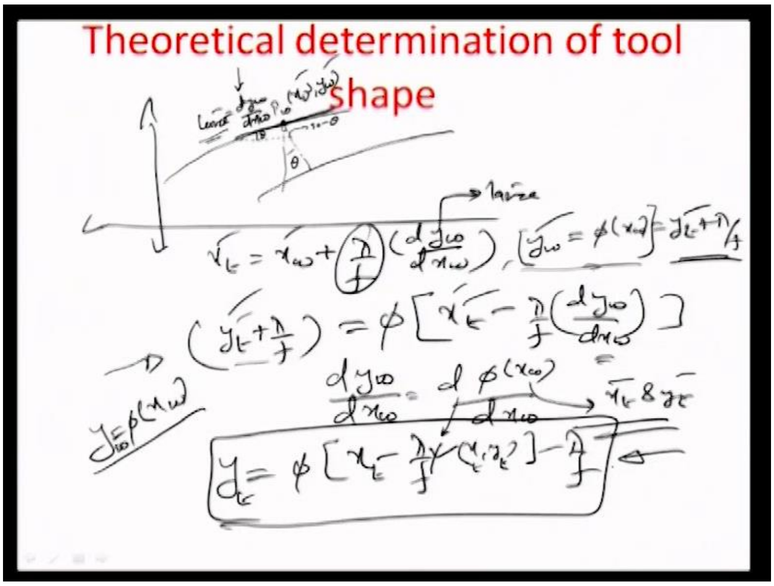

So, little bit looking at a little more fundamental way this is the surface that we are trying to integrate, which is actually the work piece surface and this is the point Pw that we are find to use to find the or map into the 2 surface. At this particular point the happens here is really in this direction right; this is the danger, at this point. And we already know that the way that surface would move is an angle of with respect of vertical direction. So, if I would just find out whether is d w by d y w by d x w here is this becomes 90 minus and this becomes theta.

So, this is actually d yw by d xw right therefore, assume that a g tan theta can be expressed as xt equal to xw plus lambda by f d yw by d xw right. This is the g, g already have the equation 3 s were we trying to save yw as a function of a xw is nothing, but y t plus lambda by f. So, if this functional relationship exists between the yw and the xw? And a we have a relationship of yw with yt and xt with xw.

We can actually right down that yw which is yt plus lambda y f is functionally connected in the same manner to xw is value here which is xt minus lambda by f times of d yw by d xw. So, if you really know the slope here then should not be a problem to map the xw yw to xt yt as available here in the functional relationship. So, therefore, the whole essence that is involved in all this is to somehow be able to write this d yw d xw. Meaning thereby, this is d pi xw by d xw in terms of xt and y t.

So, then this whole equation can be converted into all xt's and yt's and the function there in we should be plundered would be a map of xw into yw xw yw into xt yt. So, therefore, the overall representation of a tool surface provided we already have a functional relationship between in the work piece surfaces yw is 5 of xw is given by 5 x minus lambda by f some function in terms of x t and y t of x y is are all 2 sides minus lambda by f. So, this the whole napping equation from the work piece surface to the tool surface.

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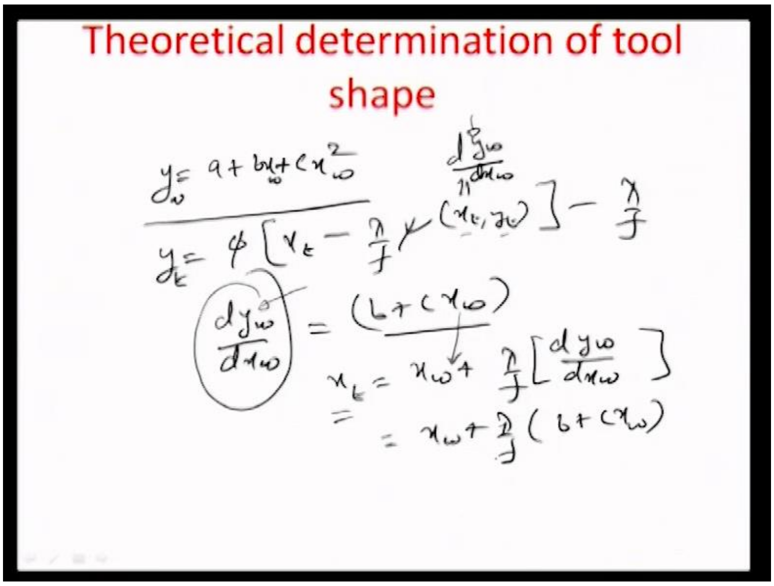

Now, supposing if we assume a functional relationship of the type y equal to let say a plus bx plus cx square for the work piece surface and you want to find out what is mapping into the tool surface. As you already know the map is provided by yt equal to psi xt lambda by f some function of xt yt which is nothing, but the slope d yw by d xw right minus of lambda by f. So, let us try to determine these to try to find out how this is related to some function of xt and yt. So, we already know that d yw by d xw is actually equal to b plus c xw right. And we are aware that the xw or xt actually is equal to the xw plus lambda by f times of d yw by d xw, which means, it is equal to xw plus lambda by f times of b plus lambda by f c xw.

So, therefore, we can either substitute the value of xw in this equation find out what xt would be in terms of what this would be in terms of xt.

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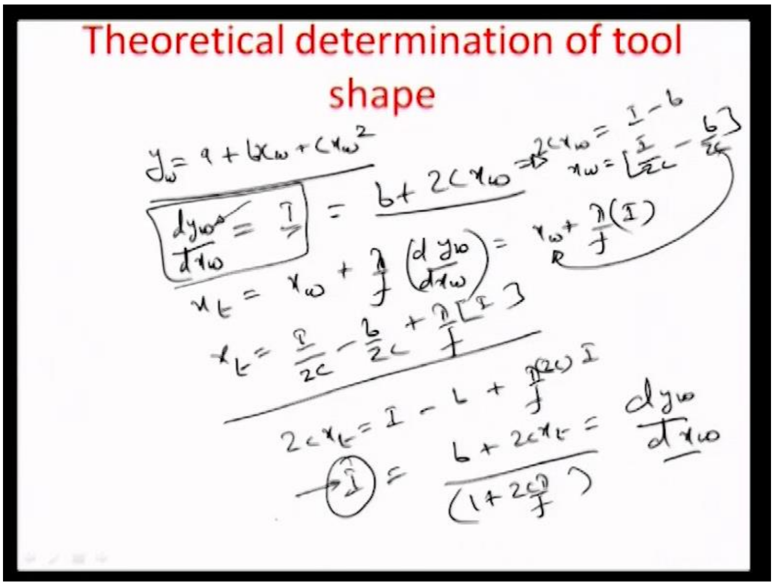

So, let suppose that there is a function y on the work piece surface which is related to x 1 the tools of tool surface by the quadratic equation a plus b xw plus c xw square. Now we want to find out how to map it from the tool of the work piece surface into the tool surface. So, you first find out what d yw by d xw is let this we equal some value I right and this is actually it can be represented as b plus twice c xw.

We already from our previous formulation for xt and xw are very well aware that xt is related to xw by the relation xt is equal to x plus lambda by f times of d yw by d xw. So, the whole efforts somehow hope should be to actually convert these whole things in terms of tools I mean in tool site. So, we can write this is is xw plus lambda by f times of I. Remember we have taken this t w the y w by d x w as I.

So, very easily we can see here that if supposing we write xw in terms of I would becomes twice c xw is I minus b or xw becomes equal to I by 2 c minus b by 2 c right. And if you put this value here we get the value of xt as xt equal to I by 2 c minus b by 2 c plus lambda by f times of I. So, obviously this should mean that multiply the whole thing by 2 c we have 2 c x t equals I minus b plus lambda by f times of 2 c times of I. Or in the value of I in terms of value xt comes out to be b plus twice t xt divided by 1 plus twice c lambda by f. So, that is how you can formulate d xw by d yw by d xw.

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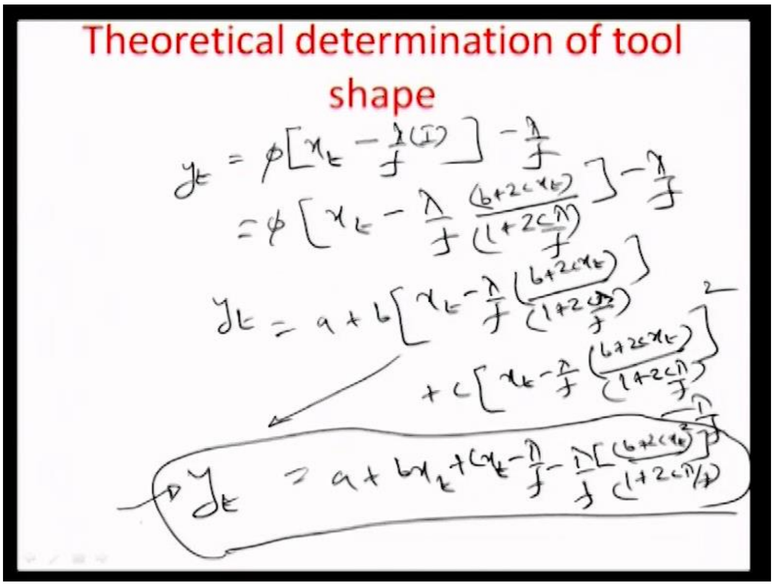

So, if I go to represent this I back into a the formulation for a y, you already know the yt in this particular case is related to the xt as yt equal to phi function phi of xt minus lambda by f times of I minus lambda by f. And this really means that this course and xt becomes equal to xt minus lambda by f times of the I value that has been decide from before as b plus twice c xt divided by 1 plus twice c lambda by f; so minus lambda by f.

Then of course you already know that yt therefore, is written as a function of 5 here which means it is a plus b times of this argument which has been formulated. So, we are not ignore the function plus c times of xt minus lambda by f b plus twice c xt divided by 1 plus twice c lambda by f square minus lambda by f. In other words, if you simplify the expression here this should be coming out as a plus b x t plus c x t minus lambda by f minus lambda by f times of b plus twice c x t square divide by 1 plus twice c lambda by f.

So, that is how you can map a quadratic function on the work piece surface to a tool surface. So, in this is just generic representation of if the suppose is the surface is defined by a function what will happened. Now, if you look at the theory that is associated with the CAD designing processes. The CAD designing also looks into local functions like this and tries to fit some of the formulations like or let say you know spline fits between either 2 points or many points. And this somehow has mapped into the corresponding negative work piece surface.

So, the best way to do it is to keep in mind equilibrium gap keep it mind that the surface going as a certain angle to this you know tool surface. And map it by a function mapping from of the x y on the work piece surface to the tool surface for a certain simple equation like quadratic equation has been demonstrated here. But then if there is a complex function which is used for fitting contours or you know complex contours of topologies that function can also be mapped.

So, the idea is that the whole design that is there of the work piece, but the requirement of the work piece something would designed in bit some pieces. And this each can be represented by either a group of functions or just a function or some of them are just linear. And then you simply the map to those points onto the corresponding tool surface and obtain that the tool surface. So, the tool design can be arrive at theoretically. So, that is a very good aspect of the process that you can actually develop a tool surface exact negative of what is there on a complex design of the requirement of the work piece. So, with this in mind we just try to do a numerical problem; try to solve the numerical problems.

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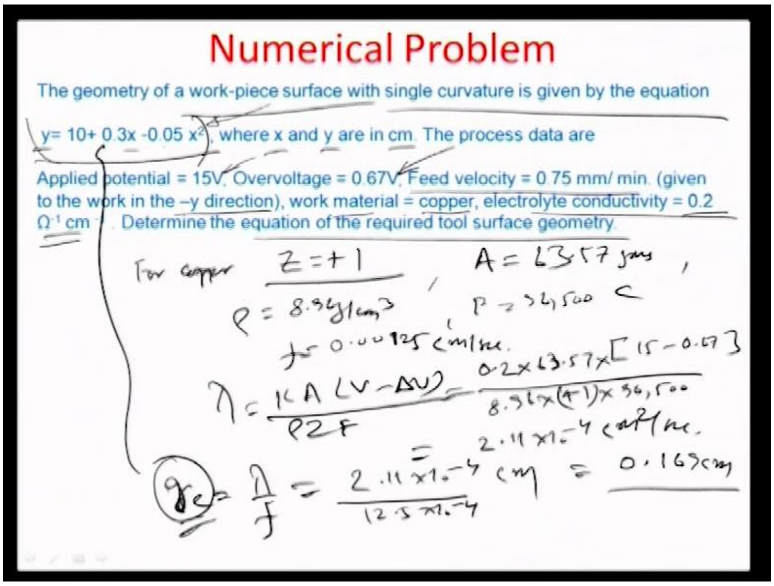

Here, as you see here the geometry of a work piece with symmetrical is given and this geometry is given by the equation y plus 10 y is equal to 10 plus 0.3 x minus 0 point 0 x square. Or you know that these are values in centimeters and the process data is that applied potentially 15 volts over voltage which is needed is 0.67 volts.

Feed velocity of 0.75 millimeters per minute and is given in typically the minus y directions. And the work material is copper electrolyte conductivities are about 0.2 ohm universe and centimeter universe you have to determine the equation of the required tool surface geometry. So, once again I would like for the sake of reputation to retrace this point, that a CAD geometry is a complex system which is created out of many such functions, which is tended functions, either representing or presented by non parametric or parametric equations.

Some linear connections between the many complex functions and then some fits; the fits are because sometimes you need to really express a very closely complex topology. And there is no other choice, but to force fit a sort of function like may be the Basier function or the b function or just a normal cubic Hermitian function polynomial to ... In a manner that by knowing just by slopes on both hands or the or the different or maybe 1 or 2 point some maybe all the points, you can try to develop a fit that way.

So, that fit then these tended functions which are already there representing the surface and the linear functions. Now, very safely we mapped topologically to develop the exact negative replace. So, the purpose of all theoretical analysis is to ultimately arrive at a tool surface given a model of a work piece surface. So, let us look at this is a very simplistic case you have already defined the single curvature of the equation given by this quadratic form. And we want to find out that for copper we assumed let say a monovalent state which is coming out.

So, we are assuming z to be plus 1 the atomic wade of copper the work material 63.757 grams. And the row here the density functions here is actually 8.96 grams per centimeter cube and the value of f here is 96,500-coulomb. And we want to find out provided the feed is given to be 0.75 millimeters by minute or another word 0.00125 centimeters per second. You want to find out what the g value is which is lambda by f and lambda can be the presented as KA V minus delta v divided by rho z f with atoms are all as you are done many times meaning their own you know, they encompassing their own definitions.

So, the case the conductivity is given to be applied give the 0.2 ohm universe and centimeter universe. So, 0.2 times of copper 63.57 times of the total potential which is available minus which is 15 minus 0.67 divided by the row value which in this particular case is about 8.96 copper times of mono volumes states of plus 1 times of 96,500 qualms. So, that is how the lambda is and this would come out to be about 2.11 10 to the par of minus 4 centimeter square per second.

Of course the lambda by f can be 2.11 10 to minus 4 by 12.5 to minus 4 centimeter in this 0.169 centimeter then comes out to the equilibrium gap y e or g e whatever you may think appropriate. And this gives as a basis of plotting this functional relationship between y w and x w and I t n x t.

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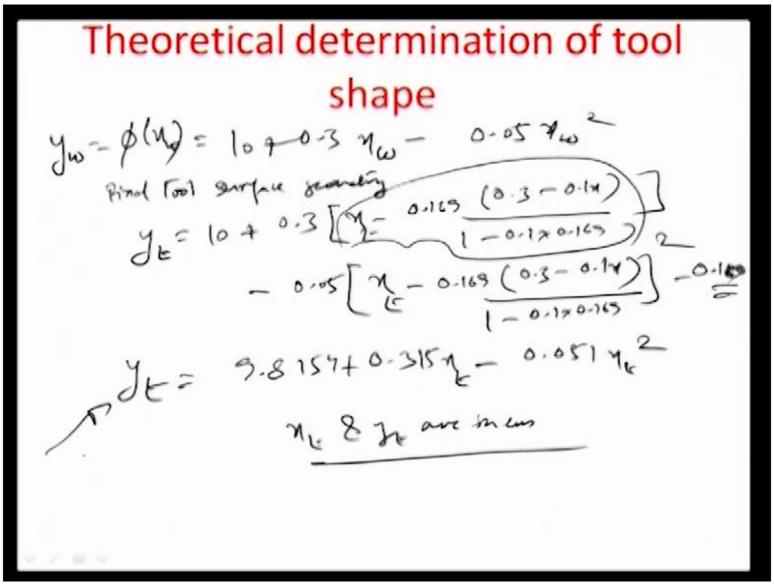

So, that lets now have a look at the final formulation. So, the work piece side you know that 5 x w is related to the y w the equation: 10 plus 0.3 x w minus 0.0 5 x w square. And you know that the final tool surface geometry as we already derived before quadratic equation can be represented as y t equal to 10 plus 0.3 times of h minus 0.169 times of 0.3 times of 0.1 h divided by 1 minus 0.1 times of 1. 0.169 minus of 0.05 times of square of this agreements.

So, this is that argument value if we may remember which was including the slope and which was you know including the slope in terms of x t and the y t value and so this 0.05. It is same argument 0.169 0.3 minus 0.1 x divided by 1 minus 0.1 times of 0.169. The score of that value minus 1 point 0.169, which is the lambda by f of the equilibrium gap term in this expression. And so if you solve all this you get a relationship between the xt and the yt and xy t is a 9.815 times plus 0.315 xt minus 0.0 51 xt square were both xt and yt are in centimeters.

So, basically this is the very good of giving a sort of optimum tool shape or a single curvature which is already given by a quadratic equation for the ship. So, I think today we are kind of the end of the lecture. We have learnt how to derive some of the very fundamental aspects of velocity of the electrolyte by moving through the gap. And we have also learned that, how critical it is because you know it will essentially validated to the pressure we should be added determine of the maximum level of the velocity. And on the minimum level of the velocity would be determined by the temperature requirements which would ensure that, there is no boiling action.

We tried to applying this fundamental problem to see what are the surface finish related defects which come in a initial process. Thereby, we learnt lot of you know different corollaries which happens like for examples or for example, the flow separation of the Eddies or the hydrogen gas generation we changes local conductivities and it always a problem with the ECM. Because, the local roughness would tempt to change and the local current densities because of that would be higher. And you can have selective dissolution which creates further problem by calling the electric fields.

You can have a case were more hydrogen is generated because of we the conductivity goes up or the sub the flow separation or the Eddies thereby meaning the local precipitates deposited at different places were the local conductivity changes would result in more or less current densities. So, these are some of the very prominent problems which are resalable with the ECM system.

The prominence goes high as you to micro system fabrication which such e c m processes we also try to determine the tool shape were we investigated how you can topologically map 1 tool surface to other in the other aspect of tool is the electrolyte flow design, which will off course try to complete in next lecture. Because, the way that insulate tools edges the way that you create you can do it for the flow of the electrolyte from the tool onto the work piece zone. Decides a lot of machining parameter for the electro chemical processes such and so would like to investigate these 1 by 1 in the next lecture.

Thank you.