Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Manufacturing Process Technology – Part- 2

Module- 21

Temperature and Pressure rise during ECM

by
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Hello and welcome to the this manufacturing.

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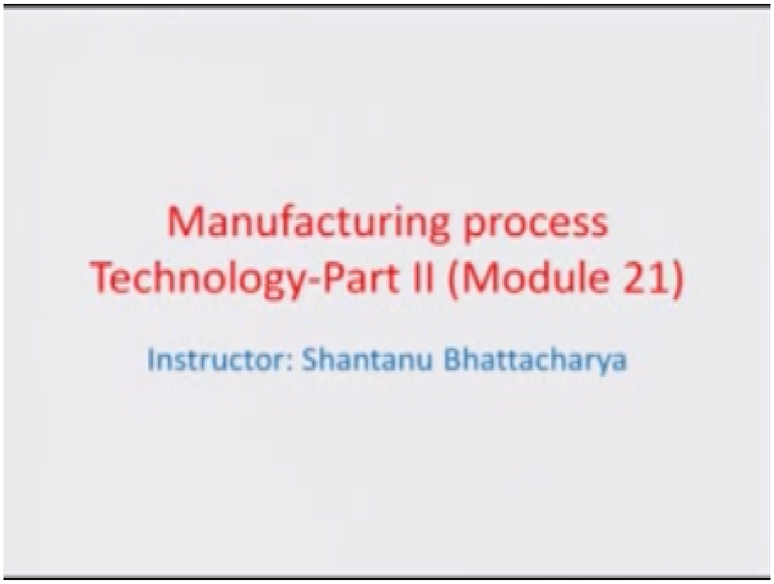

Manufacturing process Technology-Part II (Module 21)

Instructor: Shantanu Bhattacharya

Process technology part II module 21 and today I would like to talk little more about the kinematics and dynamics of ECM process.

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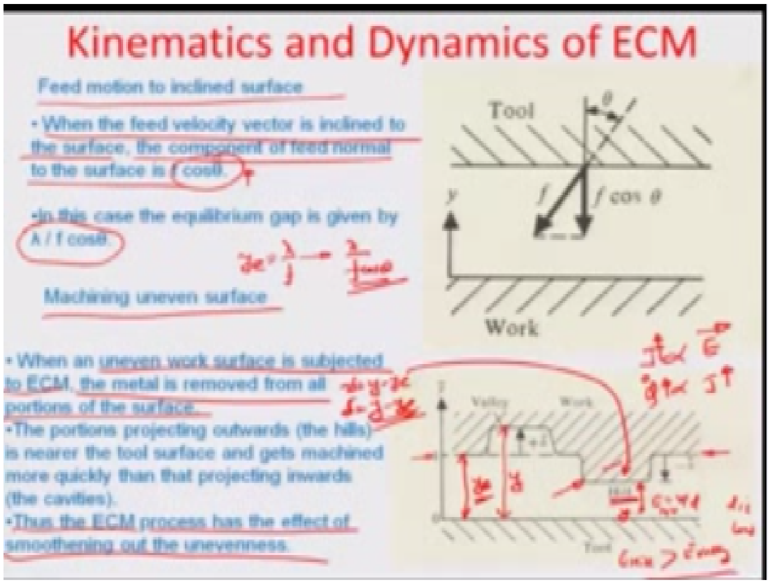

Kinematics and Dynamics of ECM

Feed motion to inclined surface

- When the feed velocity vector is inclined to the surface, the component of feed normal to the surface is f cosθ.
- In this case the equilibrium gap is given by λ / f cosθ

$y_e = \frac{\lambda}{f} \rightarrow \frac{\lambda}{f\cos\theta}$

Machining uneven surface

- When an uneven work surface is subjected to ECM, the metal is removed from all portions of the surface.
- The portions projecting outwards (the hills) is nearer the tool surface and gets machined more quickly than that projecting inwards (the cavities).
- Thus the ECM process has the effect of smoothening out the unevenness.

We are doing in the last module and in the last module we had seen that how we could scale now the equations the characteristic equations which would determine how the electrode the inter electrode gap would vary the function of time, and we also further talked about how the scaled ratios may actually result in a situation with the y dash value goes to one that means the y actually approaches the equilibrium gap y at a large sense of time which is more less t dash tending to almost ∞.

So today we are going to look at the slightly different aspect one of them obviously if what happens if the feed motion is not a sort of perpendicular to the electrode but at an inclination with respect to the electrode surface and when the fed velocity vector is inclined to the surface the common approach that is taken is that component of the feed normal to the surface is considered to be actually the feed, which would result in the dissolution etc. So in this case the equilibrium gap now would be given by instead of λ/f = ye.

It changes to λyf cause of θ okay, so this is the component of the feed if the electrode is moving at the mangle θ so it is a component of the feed perpendicular to the electrode surface that we are assuming in this particular case, to be the actual feed the other issue that I wanted to discuss is basically what happens when your machining a new one surfaces so when an uneven work surface is subjected to ECM as you know that ECM is sort of a level so it actually self levels these surface that we are machining.

And metal is remove from all the portions of the surface so let say if we have some portions projecting outward of a surface for example this is a portion which is projecting outward of this plane surface given by this and doted the line you know I means this particular figure, so this surface which can be recorded is a hell projected outside it is obviously much nearer to the tool in comparison to a surface which is away which is also recorded as a value okay, so obviously because the distance is lesser.

The field in this particular cases more so the e which is equal to v/ d in this case of the distance is less d is low okay is going to be higher in case of a helped in comparison to the values so e hell is > than e value, so obviously you all also where how the current density vector j is actually determined by looking at what is electric field which is there in the electrode and so the electric field is higher the current density vector also, is going to be higher meaning there by that the material removal.

Rate you know Q dot which is again a function of the current density vector will also be higher, so the heels get removed more easily then the valleys okay and so therefore ECM generally is a sort of a smoothening process okay, so all uneven surfaces are self smoothen or surface leveled because of this factor of variation of the electric field with respect to the tool site or the tool electrode, so let us now look at some of the issues related to this uneven surfaces we assume here certain things that.

Let us say if we make this gap right here to be the equilibrium gap at the equilibrium position by e where you can say it is a condition where the dissolution rate is similar to the rate at which the feed is happening okay, so corresponding to ye = λ/ f condition that we have discussed in the last steps, so we want to see how the unevenness can be mapped in such a situation so in this particular case for example the unevenness plus Δ in so far as a valley is concerned would be actually give by the actual y.

Which happens to be the distance of the valley from the tool surface – the equilibrium gap ye okay that is how you can record the difference δ you can call it + δ or just normal δ as Y – YE signifying that this is over an above the equilibrium gap because of the unevenness which is present on the work piece surface.

Similarly you could have a hill recorded by – δ which would be again Y- YE in this particular case where the Y actually is lesser in comparison to the Y, so that is how you see or characterize all the peaks and all the valleys which are there in the work piece with respect to the toll once the work piece has come with equilibrium gap with respect to the tool, we assuming the toll surfaced to be smooth although that is really not the case.

You can actually add the tool surface roughness also in this manner in order to project what these δ values would be.

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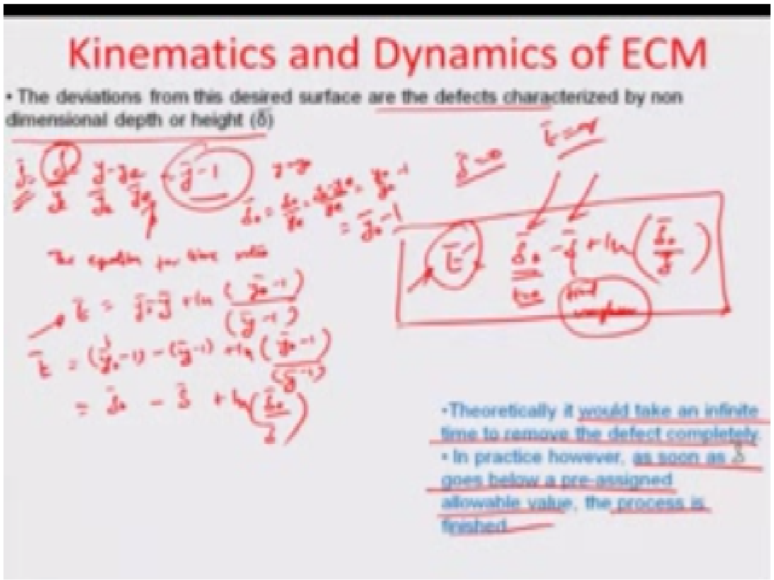

Kinematics and Dynamics of ECM

- The deviations from this desired surface are the defects characterized by non dimensional depth or height ($\bar{\delta}$)

- Theoretically it would take an infinite time to remove the defect completely
- In practice however, as soon as $\bar{\delta}$ goes below a pre-assigned allowable value, the process is finished

So the deviations from the desired surface re the defects characterized by non dimensional depths or heights δ' let us look at how we will figure out the δ', so obviously we have one instance here δ is Y – YE as a head pointed out earlier and so if I divide it this by Y in general YE in general that means I want to just map what is the δ in terms of the equilibrium gap YE and call this the gap you know the uneven ration just as we had the cap ratio earlier so we can gave δ ‘ = Y’ – 1 as our characteristic expression, so we already have the equation for time from earlier borrowed from earlier equation or time ratio or the time variable T’ to be represented as Y0’ – Y’ + LN Y0’-1/ Y’ -1.

So let us look at if we can figure out something related to the uneven ratio or the you know unevenness non dimensional number δ’ just by assuming δ’ to be Y ‘ – 1 in mannerly derived earlier here in this last step so therefore the we can say that this Y 0 this equation can further be written down as Y0’- 1 + sorry – (y’ – 1)+ the natural log(y0’- 1)/ (y’ – 1) so this can be assumed to be a condition where y = y0.

So therefore we can call δ or we can assume δ0’ to be equal to δ0/ YE which is actually equal to the y0 at time point T = 0 – YE/YE so this could be Y0/YE – 1 other words we can call it Y’ -1,Y0’- 1 so Y0’- 1 obviously is δ0’ and similarly Y’ – 1 is δ’ so I have now an equation completely in terms of gap ratios given the so unevenness ratios given the gap ratios Y0’ and Y’ as T = δ0’ – δ’ + the natural log (δ0’/δ’).

So this is how the unevenness ratio varies so this is the unevenness at time point equal to 0 and this is the final unevenness or final roughness you can say of the surface so the final roughness is obviously a function of T this is T’ I am sorry and also is a function of the initial roughness δ0’ as has been illustrated in this particular equation, okay. So theoretically it would really taken infinite time remove the defect completely.

Or in other words you approach a situation where this δ’ is 0 theoretically the T’ should be equal to infinity or that kind of a situation so that does not happen okay. But practically speaking in how as soon as δ goes below a pre-assigned a global value the process is finished and that is about be final roughness that can be obtained from an ECM process and it is something which is of importance again for the industry as well that what is a level of roughness upto which you can finish a surface, so ECM is although a self leveling self evening process of otherwise uneven surface it cannot go beyond the capacity of the process to do the you know self leveling and so that is the limited, this is the limited Δ that would finally arrive at which is also known as the process tolerance in an ECM, okay. So that is how you take care of this term here called process tolerance in ECM. Let us now try to look at again the $\bar{t}$, Δ characteristics just as we did the $\bar{y}$, $\bar{t}$ characteristics.

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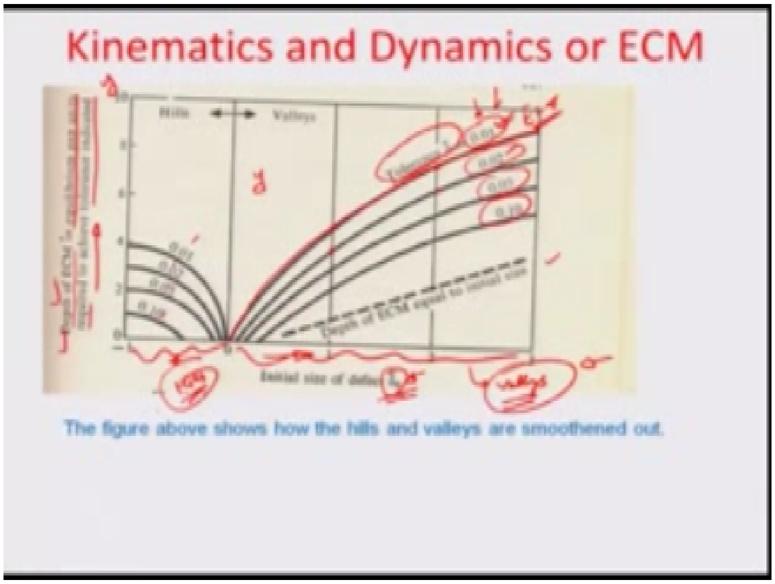

Kinematics and Dynamics or ECM

The figure above shows how the hills and valleys are smoothened out.

So here in this particular illustration for example on the y axis it is clearly shown depth of ECM in equilibrium gap units required to achieve the indicated tolerance level and the tolerance level that is indicated is mentioned here is 0.01, 0.02, 0.05 and 0.10 so typically if this is the finished tolerance corresponding to let us time $\bar{t}=\infty$ or you know this is the capacity of the processes I was talking about earlier, the way that this depth of ECM in equilibrium gap units would vary with respect to the initial defect size $\Delta 0$ lies on this particular curve, okay.

So if we start with some initial defect size okay, we can actually predict what is going to be the depth of ECM that is needed to start with okay, where you would actually hit up on a certain final tolerance Δ so that way you could actually look at this graph as sort of a thumb rule or a you know a parametric curve to estimate the start point you know the value of y really from which you need to start for the tolerance system to approach a certain level.

And here as you can see that when we talk about the positive $\Delta 0$ meaning thereby these are all corresponding to the valleys okay, so the valleys are a little more harder to machine than the hills which are corresponding to the $-\Delta 0$ side and so the valleys get removed less easily in comparison to the hills, okay. So that is how we can sort of predict the tolerance is the final tolerances of an ECM process.

So let us now work out numerical examples to find out whether we can really estimate the equilibrium gap you know considering certain aspects are related to the ECM process like for example if we have the design over voltage the design voltage and some of the other material removal rates etcetera that can be predicted in this manner from conductivity of the solution atomic weight etcetera can be really predict the equilibrium gap, okay.

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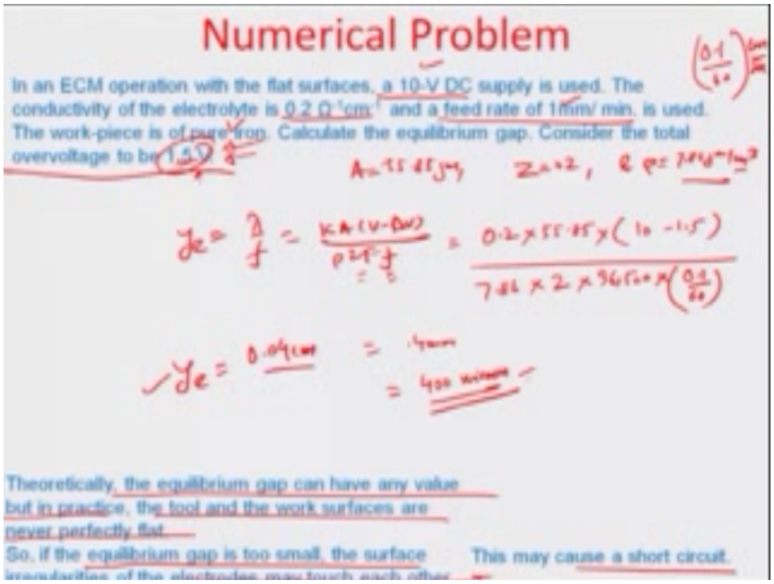

Numerical Problem

In an ECM operation with the flat surfaces, a 10-V DC supply is used. The conductivity of the electrolyte is 0.2 $\Omega^{-1}cm^{-1}$ and a feed rate of 1mm/ min. is used. The work-piece is of pure iron. Calculate the equilibrium gap. Consider the total overvoltage to be 1.5V.

$\left(\frac{0.1}{60}\right)$

$A = 55.85 gm$, $Z = 2$, & $\rho = 7.86 g/cm^3$

$$y_e = \frac{\lambda}{f} = \frac{KA(V-\Delta V)}{\rho Z F f} = \frac{0.2 \times 55.85 \times (10 - 1.5)}{7.86 \times 2 \times 96500 \times \left(\frac{0.1}{60}\right)}$$

$$y_e = 0.04 cm = .4 mm = 400 microns$$

Theoretically, the equilibrium gap can have any value but in practice, the tool and the work surfaces are never perfectly flat.

So, if the equilibrium gap is too small, the surface irregularities of the electrodes may touch each other

This may cause a short circuit.

So let us say in an ECM operation with flat surfaces 10 volt DC supply is used and there is no over voltage of 0 1.5 volts that you need to assume, I would like to also maybe drive into an area where we eventually predicted as I had earlier illustrated through our dπ equal process what would be the ζ potential of a surface okay, against which the electro light flow must happen for electro chemistry to occur, okay. So this is also a part of such then, of the overall over voltage potential, so I am just giving a value here for E's of working out the conductivity of the electro light is given to be 0.2Ω inverse centimeter inverse and a feed rate of 1mm/m is used and the work piece is made of pure iron so the characteristic properties that we assume here as corresponding to an atomic weight of iron which is 55.85gms we assume the lowest where dissolvable balance state of +2 iron comes into ferrous ions on the density how iron which is 7.86gms/cm^3 and if we look at now the equilibrium gap ye which is otherwise given by λ/f in other words it will be given by KA(V-ΔV)/ρz into faraday constant F times on the feed rate in millimeters in cm/s.

So because we want to convert everything into centimeters units and second units because current again is represented in that manner so we are now have here substituting the value of K 0.2 times the atomic weight which is 5.85 times off total available voltage, the voltage minus over potential 10-1.5 divided by the density of the material times valence times 96500 coulomb times the feed rate here which can be recorded as .1 cm/60 seconds so this is in terms of centimeter per second .1/60.

So we just record this value here 0.1/60 and so if we calculate the ye value comes out to be equal to 0.04cms or .4 millimeters okay corresponding to above 400 micron so that is how ball the equilibrium gap comes out to be in such a case so theoretically the equilibrium gap can have any value but in factors the tool in the work surfaces and never perfectly flat and so it depends on what is the average roughness which would determinants of this term ye.

So if supposing the equilibrium gap is too small then the surfaces may match each other and this may cause a short circuit because of irregularities of the electrode surface so this something that we have to avoid in an ECM crosses touching or the short circuiting of electrodes to the differential surface roughness.

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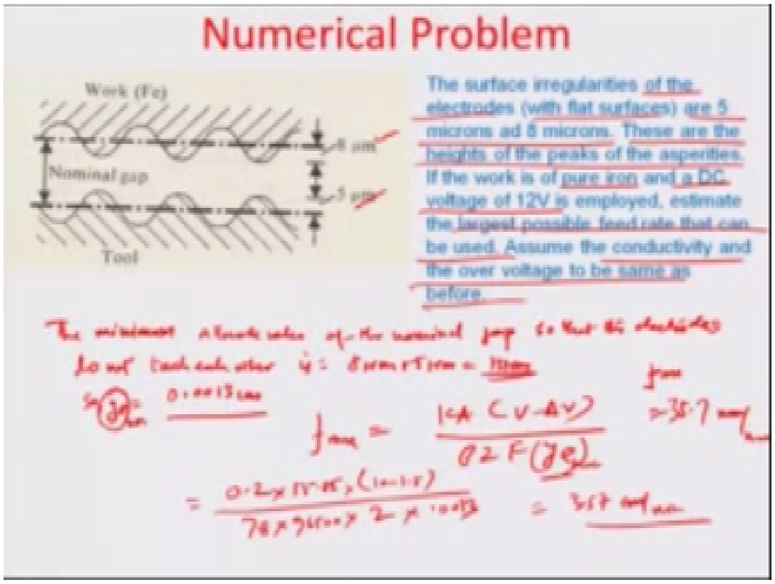

Numerical Problem

The surface irregularities of the electrodes (with flat surfaces) are 5 microns ad 8 microns. These are the heights of the peaks of the asperities. If the work is of pure iron and a DC voltage of 12V is employed, estimate the largest possible feed rate that can be used. Assume the conductivity and the over voltage to be same as before.

The minimum allowable value of the nominal gap so that the electrodes do not touch each other is = 8 μm + 5 μm = 13 μm

$(y_e)_{min}$ = 0.0013 cm

$$f_{max} = \frac{kA(V-\Delta V)}{\rho Z F (y_e)}$$

$$= \frac{0.2 \times 55.85 \times (12-1.5)}{7.8 \times 96500 \times 2 \times .0013} = 35.7\ mm/min$$

f_{max} = 35.7 mm/min

So let us look at the other problem example which talks about the minimum possible equilibrium gap that needs to be maintain even the certain surface roughness value that has been provided so let us say in this particular case the surface irregularities of the electrodes with a flat surfaces are

5 micron or 8 micron frequency the regularities plotted here this obviously very evenly realized the surface real life situation is not so even.

So the surfaces are going to completely random in that case so in that event the surfaces that you would or the parameters that he would take to determines really the Z maximum you know for both the surfaces so these are the heights of the peaks asperities in the work is pure iron and DC voltage of 12 volt has been employed.

You have the estimate the largest possible filtrate that can be used in this particular condition in other words filtrate and the equilibrium gap are almost live to each other so you are estimating what is going to be the minimum equilibrium gap at which you can operate so assume the conductivity and the over voltage to be same as the previous example.

And also assumed that the surfaces are might up of iron so having said that the minimum available value of the nominal gap so that the electrodes do not touch each other is given as 8 microns+5 microns that is about 13 micron meters and therefore the ye or the equilibrium gap can be recorded as 0.0013cm okay.

So once this ye is recorded it is very easy to calculate the maximum feed rate which would depend on KA $V/\Delta v/\rho_z$ F times of this ye and this ye maximum or ye minimum that can be allowed as been given out to be 13microns so if I substitute the values of k 0.2 55.85 times of the same potential over potential divided by 7.8 times of 76500 times let us say +2 valances state times the 0.0013 cm what I get is 3.57cm or minute other words I can go at a maximum feed rate of 35.7mm per minute.

So that is how you can consider the maximum feed rate to be in this particular example problem. So I think now you should be enable to sort of do some numerically designed problems about how to predict the equilibrium gap the minimum equilibrium gap the maximum feed rate so on so forth if you get across as an ECM setup and try to start doing C machining. The other issue that is important for me to tell or share this level is that it is very important to ensure that the heat transfer process which are working in a ECM set up are well managed or well balanced.

And one of the reasons why that is shows that the electro light starts behaving phonically and it is a conductor and so obviously there is going to be heating of the electro lights. So we can think of that the electro light serves as sort of a heat sink which goes in to the working zone gets all the heat and because it is a flowing electro light it is actually a working fluid for the heat transfer from the electro to happen.

So if you assume a simple one dimension model we should be able to ensure that the temperature of the electro light never goes above its melting point so that there are no problems related to bubbles etc. bubbles can be of series consequence in ECM I am going to probably do this in great details once we talk about surface finishing and what are the kind of issues which I involved in the ECM process.

But as of now I would like to just illustrate that there is something called as velocity design ion the ECM process and the next step that we have follow is to sort of try and see we can get the velocity of the electro light flow in ECM set up which gives you workable system where there are no evaporation issues there are no bubble formations of the electro light in such a setup. So let us look at this temperature and pressure during the ECM.

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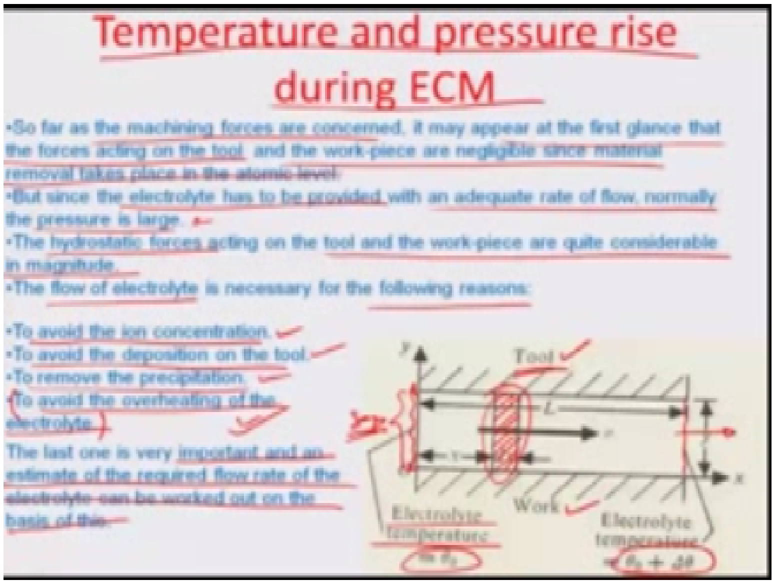

Temperature and pressure rise during ECM

- So far as the machining forces are concerned, it may appear at the first glance that the forces acting on the tool and the work-piece are negligible since material removal takes place in the atomic level.
- But since the electrolyte has to be provided with an adequate rate of flow, normally the pressure is large.
- The hydrostatic forces acting on the tool and the work-piece are quite considerable in magnitude.
- The flow of electrolyte is necessary for the following reasons:

- To avoid the ion concentration.
- To avoid the deposition on the tool.
- To remove the precipitation.
- To avoid the overheating of the electrolyte.

The last one is very important and an estimate of the required flow rate of the electrolyte can be worked out on the basis of this.

And we will just simply use one dimension problem here so far the machining forces are concerned it may appear at first glance that forces acting on the tool and the work piece and negligible since material removal takes place atomic level but since the electro light has to be provided with an adequate rate of flow normally the pressure is large. So this is something that we must understand.

Number one the gap of an ECM set up is very small because of the minimum equilibrium gap that is possible it depending on the surface roughness level of both the electrodes. So when you pass a fluid at a certain velocity through such a small gap so there is obviously going to be lot of shear between the surfaces concern particular the electrodes surfaces and the rushing electro light and the shear is always resulting in a pressure which would be in the typically the reverse direction of the flow and so that is one aspect and obviously when you are moving you know an arrow gap the when the surface is more prominent the factors which are related to the bulk or volume flow of the fluids becoming significant compared to the surface, related factors. So the hydro static forces would although act on piece, they are cost because of the shear as well as the hydro static pressure and sometimes it may lead to the warping of the electrodes and the condition that needs to be arrived at, the pressure because of shear or any other factor okay.

Would not increase or exceed the ultimate heal strength of the material. So therefore it is very important to design the electrolyte flow in such a manner, so that you do not avoid the iron concentration to take place so that it is not that as if in 1 area or in one section there is more machining in compare to other because of the extremely high concentration which accumulates in different areas, you should avoid the deposition on the toll. That is another reason why flow should happen of the electrolyte.

It should be able to remove the precipitation whatever you know that the ECM process is all about and getting percepts, so somebody as to able to swipe the area of which is getting formulated. So flow is very important for that aspect and also to avoid over heating of the electrolytes and also to ensure the pressure rate in the reasonable level. We need to ensure that the electrolytes flow that is pre designed.

Last one this overheating and off course the pressure there in is a very serious consequence, it is very important and estimate of the required flow rate of electrolyte has to be worked out, just because of such a problem which ECM set up. So I would like to start with this model from the next module, but I would like to mention the basic premises that we would have to take a count for modeling.

So you have now tool surfaces as you can see here and we assume that the electrolytes as to flow in at a certain temperature from this end of ECM and it goes out from the other end of the ECM where the electrolyte temperature gets elevated because of heat transfer which would happen from the tool into the electrolyte. So having said that we would like to just analyze a small element of the fluid of thickness ex which is otherwise spaced for a certain distance to plane here.

Although it is 2 dimensional problems assume this to happen, we can consider the distance into the plane in z direction to be unit but even if you do that by considering some distance. Let there be some distance, so essentially talking about the cuboids element of the electrolyte and you would like to consider the current flow across the cuboids element because of the current flow. So we will do this model at probably with related modules and I am going to close on this module in the interest of time, so thank you very much for being with me.

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