Microsystem Fabrication with Advanced Manufacturing Techniques
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Lecture – 21

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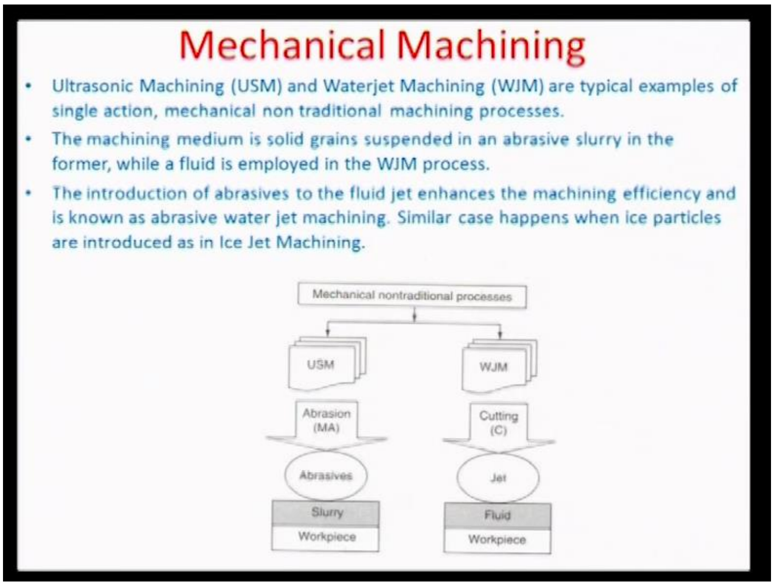

Hello and welcome back to this lecture twenty one on micro system fabrication by advanced manufacturing processes. So, a brief recap of what has been done. So, far we have talked about different mechanical processes ultrasonic machining, and abrasive jet machining or part of blasting, and then we have also discussed some applications related to memes design, and memes fabrications such as micro system fabrication by virtue of using some of these mechanical processes removal material removal processes, and as we saw that most of the time, it is bulk micro machining it is removal subtractively of the material from the bulk of the wafer which creates micro structures, and features using some of these mechanical processes mechanical fabrication processes.

So, in principal what happens is it is the deliverance of mechanical energy by abrasive materials or some other medium may be it is a slurry containing abrasives which actually hits the surface concerned, and tries to abrade the surface away. So, that the features can be produced, and if it can be guided through masking step or a masking process, then the features can go extremely small, and you can actually realize micro features, and micro structures.

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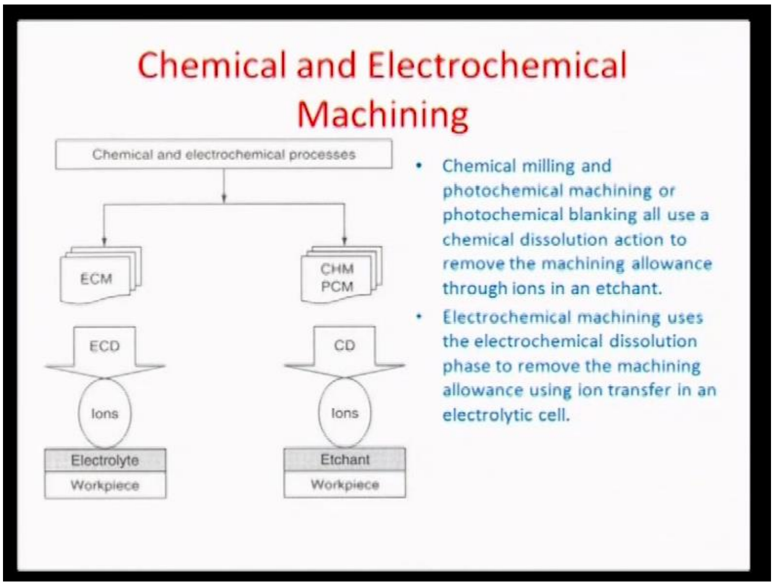

We also talked about some of the chemical electro chemical machining processes where on one instance it is basically the power of electrolysis using the faraday loss, which actually leads in selective removal of material of deposition of material depending on whatever the requirement is, and then there are corollary are associated processes the bunch of battery of bunch of processes with the electro chemical machining like e s d electro stream drilling electro chemical grinding e c g or electrochemical drilling e c d processes.

So, you basically what you use is that you know you have conducting electrodes, and one of the electrodes is the tool rather is the work piece, and you can selectively by electrolysis remove the material, and we also did chemical machining at beginning of our lectures when we talked about photolithography where materials known as resists photo resists are used for selectively creating features, and structures. So, the idea of our resisters that it gets changed on exposure to photo chemical energy of or you know photonic energy, and at a certain frequency if you expose the resist there is a photo chemical change which is induced on to the resistant terms of either bonding cross bonding or debonding, and accordingly the type of the resist can be defined as negative or positives.

So, if there is cross bonding action doing the different molecules, because of photonic explosion it is called a negative resist if it is a debonding operation which is happening it is called as positive resist. So, you can actually selectively pick, and choose certain areas, and make either crevices or features crevices or vias on the photo resist film as happens in the case of positive resist or features, and structures as happens in the case of negative resist. So, those are the chemical machining processes, and then variety of chemical machining steps can be used by a using medium which can be fluidic medium you know liquid medium or gaseous medium. For example, we talked about deep reactive ion h e where plasma is the medium which is used for selectively etching away the material on a masked surfaces suitably masked surfaces. So, you have to create a sacrificial mask which does not otherwise get effected by the plasma, and in that mask there are windows where the gas molecules can actually go inside the window attack the main substrate which is below the mask, and then based on that it creates micro sizes features, and structures on those material. So, you have a battery of again chemical photo chemical machining processes which we studied in details we also looked at some of the applications of such processes in terms of building micro systems or you know micro micro manufactured parts or features.

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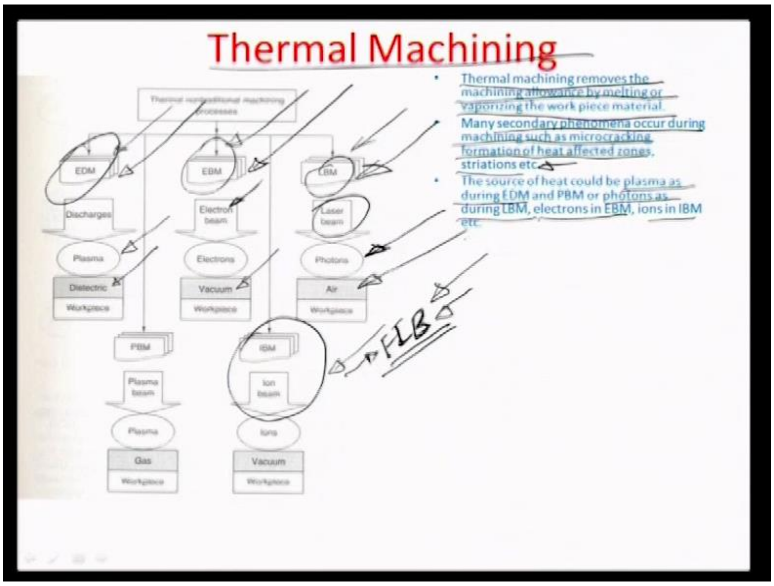

Now given all these different techniques third technique of consequential importance is the thermal technique of selective removal of material, and this technique is actually by means of using some kind of a thermal energy, and this energy can be delivered in a variety of ways on to the surface for example, be a stream of electrons which is generated either as a discharge which can remove selectively material by a process called e d m or electro discharge machining process or it can be alternately the high energy beam of electrons continuous high energy beam of electrons which is produced using thermionic emissions from a intensely heated cathode, and then subsequently guided a stream line by virtue of variety of anode perforated anode anodic electrodes.

So, that there is a narrow ultimately very narrow size of the beam which hits the surface at a certain point where it may create an effect desirable effect on the surface, because of this, and then you also talk about some other thermal processes like plasma beam machining iron beam machining, and there is a lot of micro nano size features, and structures which can be created by virtue of either transport of material using the high power of a beam. And the advantage that you has is the resolution at which you can transport this material, and make it in to distinct features, and sizes, and also you selectively removes away or etch out material using high power of a beam by increasing the power associated with the beam you are essentially creating a very high frequency low wave length beam or radiation, and the lower as the wave length as t he better is the resolution at which the beam can be (( )) over a surface which, then produces some kind of an effect related to ultimately machining of the surface.

So, the higher of the power of the beam more as the resolution of the beam this is an advantage. So,, because we have talking about micro system design or micro system fabrication if these means some of these means like e d m or e b m selectively used there is a good possibility of getting micro structures, and features well return at a certain defined resolution on the surface the important process is the interaction the light matter the you know the interaction of matter with photons, and when we talk about that the first name which comes in to our mind is laser beam machining l b m, and basically what this form of machining does is it is a interaction of a high energy beam coherently super focused high energy beam of laser, and laser stands for light amplification by stimulated emission of radiation.

So, it is a laser beam which we are trying to focus on a narrow region of the surface, and then the laser gets interactive with the matter as such, and the by virtue of this matter light interaction there is thermal energy which changes the nature of the substrate in which the beam falls. So, typically by ablation losing the laser process you can thermal evaporate a part of the substrate on which the beam is super focused. So, laser beam definitely used for doing a lot of high resolution writing on surfaces in terms of micro features, and structures. So, that is very important process from micro system stand point. So, what we are going to do in this thermal machining is to look at some of these processes like may be investigate the e b m, and l b m these to processes in great details which are very often used for micro system fabrication, and may be look in to. So, some of the e b m related processes, and then if time permits we will also talk about these ion beam machining, and there is a very modern instrument which is come up very recently for writing at the nano scale which is called the focused iron beam machine or f i b which is used for either machining like drilling operations of even at the molecular level, and is also subsequently used for both surface, and bulk micro machining.

So, one thing of importance that I would like to again retreat here in that is that in case of e d m the medium which is causing the thermal machining is the plasma beam which is discharge of electrons, and hence, and then this happens. So, medium which is typically a high dielectric constant fluid it can be something like let us say completely demonized water or it can be something like kerosene oil which is high dielectric constant fluid. So, the work piece typically flooded with that, and the iron electron column is created between the tool, and the work piece through the electric medium in case of e b m as you see there is vacuum in between. So, the effect which of striking is gathered together by a beam of a electron which surpasses a very high vacuum column, and at the other end of the vacuum you have work piece.

So, the beam interacts with the work piece by transferring the electrons kinetic energy to the bond vibration energy of the material, and that is the principal cause or mechanism of material removal if you do the machining by using an e beam. So, when talked about similarly l b m or laser beam machining it is basically bunch of photons which are coherently spaced with respect to one another, and high intensity is certainly relieves you know very small area, and the medium through which this energy is transferred to work pieces just air.

So, it is one of the simplest processes, because laser beam machine can allow work piece sizes up to any length, and breadth whereas, the more specialized processes like e b m although they are capable of writing really super fine or very small the problem is that, because you have to maintain a vacuum around work piece it is limited by the work piece size that you can really machine is limited by the nature or type of the vacuum column that you are using for housing this e beam system. So, in general there are some very some basic fundamental principal based differences between all the different machining processes that we have been illustrating. So, in general we can also conclude that the thermal machining removes the machining allowance by melting of vaporizing our piece materials, and many secondary phenomenon occurs like micro cracking of surfaces formations of heat effected zones striations etcetera, and the source of heat could be plasma as during e d m or photons as during l b m electrons as in e b m machine, and ion beam machine.

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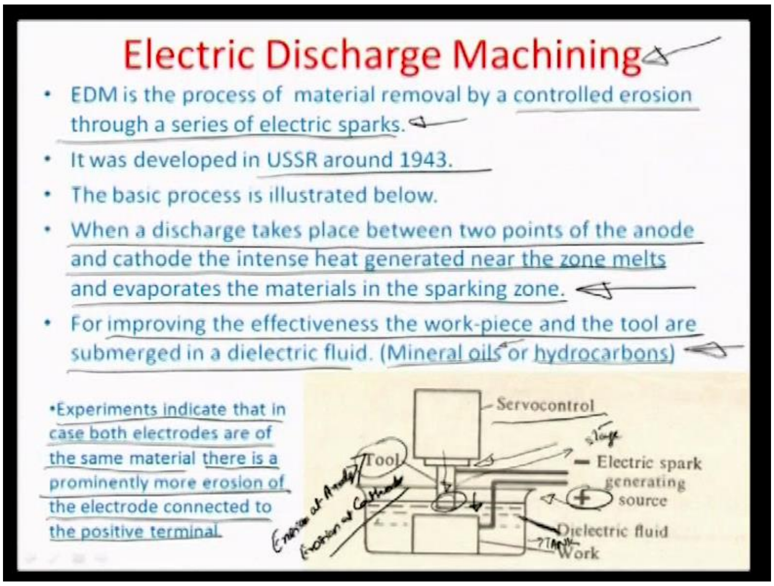

So, let us look at the first process of thermal machining that is the electric discharge machining e d m which was. In fact, which was developed in u s s r around in nineteen forty three, and it is really process of material removal by a controlled erosion by a series of electric sparks. So, it is a short discharge which we had talking about when we talk about sparks. So, it is a very brief amount of discharge of electron of a single tip, and there are several such discharges which are happening wherever the breakdown feel of the medium is exceeded by the external electric fluid, that is been applied, and there is always a removal of the electron going to that. So, let us look at this basis process. So, when a discharge takes place between the two points of the anodes, and the cathode the intense heat generated near the zone melts, and evaporates the materials in the sparking zone.

If suppose there is a difference of melting, which could happen from one of the electrons to the other, then we can successfully used that process for machine which means that in the tool side if supposing the melting rate is lower, because whatever property is tool may have, and in the work side if the same is higher than we can say that process is used or its for machining applications on machining purposes. So, it has been designed in the manner. So, this is the iron column which is established between, and work place electoral damages the work piece more appropriately than the tool electoral, and that is how the in the work piece is higher than the tool the tool does he wrote in the case of e d m, but the work piece is that much faster rate, and that creates the situation where e d m can be used successfully from size features with the good amount of machines surface allowance.

So, for improving the effectiveness of the work piece, and the tool are submerged in a dielectric fluid which can be hmmm hydrocarbons like kerosene oil or some mineral oils, and one very important accept of e d m which come during experimentation is that even if the electrodes that you are using that of the same material; that means, both the cathode in the anode has in this particular case you can see they are made of the same material hmm that is somehow if prominently more erosion of the electrode connected to the positive terminal. So, anode in this particular case is always eroded more than the…

So, erosion at anode is more than the erosion, and cathode there is very distinct reason why erosion is different, and different electrode, and for doing, and for understanding why the erosion is different we need to really look at very closely what is going on between the anode, and cathode in the e d m operation. So, let us say we talk about a e d m machine as you can see a figure in this you have a small stage which is able to heat the tool surface amounted on stage in the negative wide direction, and there is work piece which is kept in a dielectric in tank which is filled with, and re circulated with this dielectric fluid.

So, you can see this is that tank, and it is flooded with dielectric flute which is a kerosene oil or any other mineral oil or hydrocarbons, and in this manner the tool is fed towards the work piece that giving a very high filed between the tool, and the work place use typically servo control for feeding the system towards the work piece. So, let us see what happens. So, just, because has has we have experimentally sought of tried to figure out, and found that the anode erodes more intoed if thinking could allow the anode to be made the work piece, because the material rate is much more as it becomes the anode.

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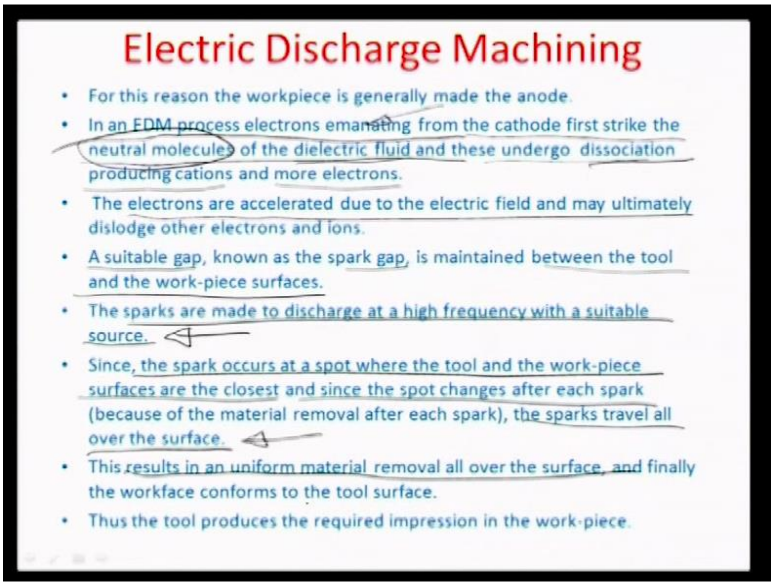

So, in a e d m process the electrons that emanating from the cathode first strike neutral molecules of the electrolyte. Let us look at before the starting the electrons emanating out lets understand the reason why the electrons are emanating out let us suppose you have two electrodes the anode, and cathode, and they are approaching one another, and certain space. So, what is going to ha change in between the electric in this set of electrodes the electric field it varies as a function of the distance as we are seen in a e d m as well as the tools move closer, and closer to the work piece the distance between the two reduces, because of which under certain constant potential you can say that the filed value is slowly increasing to the certain value.

Now suppose the in this fluid between the anode, and cathode exceeds the break down field of the medium that we are talking about, and break down field means that the situations where medium is amenable to electrical break down in other words it gives the conducting path through it or the electrons of the one side that is cathode to flow in to the anode side. So, in that situations of course, the electrons will start emanating out of the cathode, and those electrons which are emanating out of the cathode the first light that they see are in terms of those hydrocarbons molecules which are present in the execution which are immersing both the electrodes the movement they start seeing this hydrocarbons molecules they would definitely like to led those molecules go in their ionic state. So, they be they may knock of electrons, and make them positive, and there may be more, and more electrons, and irons combinations which is like a chain reaction which is set up between this, and anode, and the cathode unless whatever electrons have been discharged into the fluid Aare translated all the way to the anode side.

So, in the process of doing that, because there is a field which is riving those electrons, and irons there is always the tendency of the irons of the electrons accelerate as well, because there is an external filed which is doing a work on those set of irons, and electrons. So, therefore, the electrons are accelerated once they start emanating, and once they start breaking down the neutral molecules of the electric light. So, this is actually a dielectric fluid. So, oh the in the e d m process the electrons emanating from the cathode first the strike the molecules sort of meets in the dielectric fluid, and they are by, and large neutral molecules at the time when the electrons are first emanated into the fluid, and this dielectric fluid, then kind of breaks down, and undergoes some, and produces intern can enhance positive irons, and more electrons.

So, you breaking down the neutral medium between the oh two electrodes by the electrons which is emanating out of the cathode towards the anodes that is creating cations, and electrons, and a huge density of this is created throughout the column, and its chain reaction once the electrons starts emanating continuously from the cathode surface to the anode.

So, now if you can maintain or sustain this process oh typically what happen is this that if supposing there is a bunch of electrons which comes of out of the cathode they would can extinguish the movement the reach the anode they are grounding, and they are getting discharged, but if you can somehow sustain this mechanism of emanation of electrons from one surface to another, then you can have a situation where there can be multiple dancing sparks, which are there depending on wherever the closer proximity is between both the surfaces where the field as actually exceeded the break down field of the media, because filed is a actually a voltage per unit distance, and the distance is the minimum depending on whether it is a hill to hill separation between the tool, and the electron.

So, the e d m is made a self sustained process by generating a suitable gap which is known as a spark gap which you have to maintain between the tool, and the work piece surfaces these the sparks are made to discharge oh at a high frequency with a suitable source oh since the sparks occurs at a spot where the tool, and the work piece surfaces are the closest, and since the spot changes after each spark travel all over the surface. So, here it is very important for me to point out that any surface that we are considering has certain amount of surface roughness, it is not really a perfectly flat surface.

So, there is some oh nano meter level at least value of roughness even if it is super polished surface. So, there are going to be hills, and there are going to be valleys, and therefore, distance of the proximity oh between the tool surface, and the work piece surface where is greatly depending on what is the relative orientation of those hills, and valleys of one surface to with respect to the other. So, two hills for e g on both surfaces would have minimum distance or one hill with one valley or two valleys on the both surfaces will have the maximum distance.

So, as you already know that this emanation process of the electrons dependent on the electric field is actually inversely proportion to the distance the the point of the both the surfaces which are closest space are the once where the spark should first generate because those are the areas where a for a certain proximity between both the surfaces the highest point on one surface facing the highest point on another surface the field has exceeded the break down filed there is of the electron if I assume that if there is a selective removal of the material, because of the thermal energy which has been transported by this electron emanation from one electrode to other, and if we further assume that this energy is more emendable to removal of the material from the anode side, then the anodic hill which was there will get disappear therefore, the distance will again increase, and filed will go below the break down filed value, and there would be again another distance of close proximately which will be searched by that emanation process to again happen. So, there is a tendency of spark to sought of oscillate between two such high rises or two such hills on both the surfaces has this process continues.

So, it result in a uniform material removal eventually, because first one of the hills which are the highest with respect to the another hill of the work piece side is isolated the hill on the work piece is melted away, and then the next hill to the hills spacing is isolated, and then it is melted away. So, that way the whole surface has the self smoothing affect, because of the e d m process. So, in a this is also a like in process although the material transport kinetics is totally different it is based on thermal actuation which happens, because of generation of spark, and eventually even in this process oh whatever is the tool surface is on to the work piece surface.

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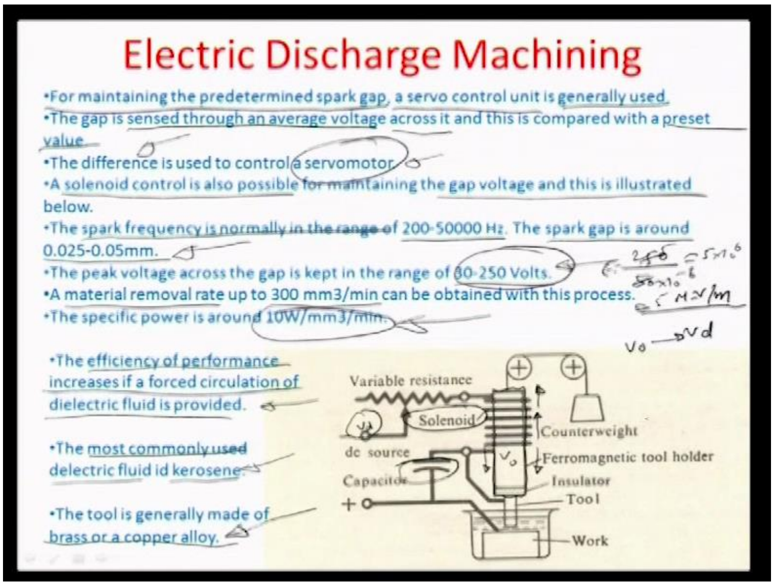

So, some other issues for maintaining the predetermined spark gap normally a servo control unit with accurate, and precise feed forward of the tooling with respect to the work piece is generally used, and there is sensing mechanism which is designed in the manner that the gap voltage average voltage across the gap that is sense, and there is a pre determined or pre set value, and you compare the gap voltage the variation there with the preset value, and to be able to estimate how much filed forward or filed backward of the tool is needed to the with respect to the work piece. So, the differences used to to control in term the servo motor which does the field forward or field backward off course control is also possible for maintaining the gap voltage, and here you can see actually how this works. So, here depending on the the voltage across this capacitor right here which is also voltage across the gap.

The solenoid can take a decision of whether to field the tool in the forward direction, and take the tool in the reverse direction. So, whatever is the voltage between these two is a reason for actuation of this this solenoid with respect to a dc source suppose in this voltage here is more than the voltage of the dc source here, then current of the solenoid flow in ah the higher voltage to lower voltage direction, and, because of that the magnetic field which could be generated try to oh take this particular electrode in the reverse direction; that means, field backward, and vice versa, and if it is higher than, then it could take electron in the forward direction some other parameters about the the process the spark frequency is normally in the range of two hundred to about fifty kilo hertz the spark frequency is really domestic process it dependent on how many hills, and how many valleys are there with respect to each other which comes face to face in the process of the ah two material being feed with respect to the work piece material although the control of the field forward is very stable, but it always can have a micro meter displays sidewise as well while it comes down, because of the high pressure that the electrical field could have between the gap, and therefore, which part of the surface comes opposite to which part of the ah of the work piece surface it is not profitable.

So, any part of the tool can at any point of time come in front of the any part oh of oh the work piece surface for example... So, it is very randomized process, and controlling spark frequency is not possible, because it is done at the domestic level by even small movements between the two surfaces. So, the gaps that we are talking about where the spark is generated is varies between about point zero to five two point zero five millimeters. So, that about two point five to. So, microns that the how small the gap is actually, and the peak voltage across the gap is always kept in the range of thirty to two hundred fifty volts. So, you can understand the kind of fields that we are talking about two hundred, and fifty volts divided by a fifty microns minus six makes the electric field is equal about five tenth to the power of six or five millions volts or meter.

So, its very, very high field that we are talking about between the small gap even at a small voltage of two hundred, and fifty volts between the two electrons now the material removal rate can go up about three hundred millimeter cube per minute. So, it is reasonable high material removal rate, and if you look at how much power is needed per unit increase in the material removal rate that is comes to be about ten volts per millimeter cube per minute; that means, if one unit of a m r r material remove rate is increased it leads to about the additional consumption of about ten volts of power it is a power intense of process naturally, because the requirement of this process is really thermal means of of material.

So, therefore, whatever the higher the better you know the more power you are sending in a focused area through its spark the better it is for the machining rate, and the material removing rate. So, the efficiency of performance for example, increases if a forced circulation which is also true you saw for the electro lights, but in case of a electro lights there was a problem that the pint of the electro light was the main design guidelines or or to set the main designed guidelines for determining the flow velocity here there is no such limits this is hydrocarbon, and although ah there is a associated with this hydrocarbon which produces a small deposition layer on the cathode particularly, because these are all components, and electrons which are generated by the emanating electrons on the hydrocarbon, but, then it is of not very high consequence there is no much significance in the of the dielectric flowing, and flow rates typically are more driven by what final material removal rates on marching rates from the process, because again you have to remember that the field is flowing across the gap, and the material which gets thermally, because of the spark has to defuse into this fluid, and fluid is also acting as a medium for the defused mass.

So, whatever the machining is being done by means of creating the melt pool on the surface is being defused into the circulating fluid, and that fluid circulation increased intern mean than more of such mass is displaced way from the machining zone. So, the m r r gets significant higher if you increase the velocity of the flow of the dielectric fluid; however, will have to concerned about the issues like laminarity, and how you know you can have this local, and which may create problems i m material removal similar manner as we talked about in the most commonly used dielectric fluid is the kerosene oil its hydrocarbon.

And the tool generally made up of bronze the copper oil, and very good fine calibration of this tool has been done in terms of tool rate also as we have initially mentioned still still to ascertain there is a reason why the tools are surface would have lesser erosion in comparison to the work piece surface even though both the surface are handling the same iron column. So, we will just look into that aspect later, but then the idea is that the metal made up of copper or bronze found suitable to a machine that a iron work pieces by virtue of e d m just by minimum possible were rate that is possible for tool surface.

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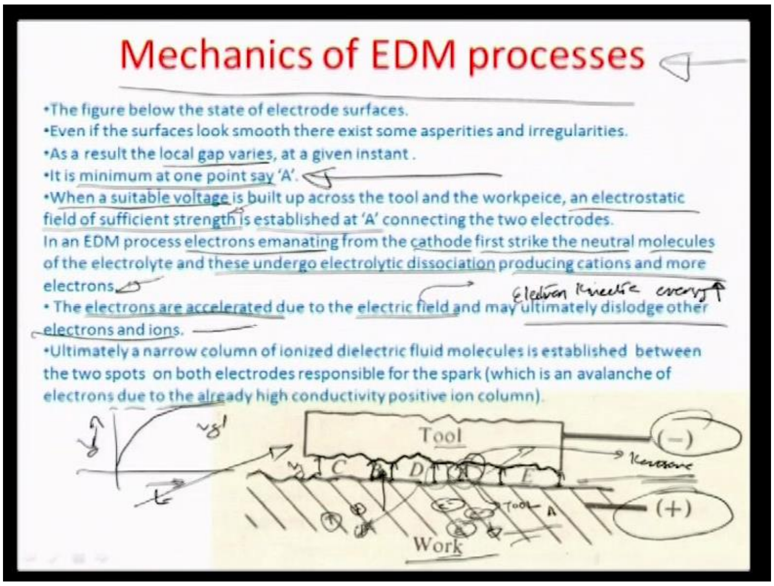

So, let us look at again the mechanics of the e d m process in the little more details s lets see for example, this figure here. We are talking about how the hills, and the valleys of one surface will place these are defeat hills, and valleys on the tool surface, and same goes to the work piece side as well the work piece also have these hills, and valleys no surface can be completely smooth there is some domestic skill roughness which exists even if it is super polished surface that we are talking about, and this we have made the work piece by connecting into the anode, and cathode and. So, the local gap is really very easy between these two surfaces based on what all features are there on the both the surfaces fetching facing each other suppose i consider this gap here with minimum. So, this minimum gap at some point of time of time, and the point is, and you have also applied suitable.

Voltage across the tool, and the work which has been build up by have the reversed time, and the voltage verses time across this gap, and this gap voltage vg build up from zero to some value, and say vg prime. So, the moment the break down field of whatever is inside here the dielectric material is a is reached there is going to be a dissociation, and there is going to be an electro static field of sufficient strength probably more than the break down field being established at a, and the movement that happens there is a discharge of electrons from this point it here on the tool. So, a point on the tool toward a point on the work piece. So, there is a electron discharge. So, the electrons emanating from the cathode.

They frostlike the neutral molecules molecules are placed in the gap here, and the, then they undergo solution. So, whatever is this the electric fluid gets associated, and this produces cautioned, and more electrons cations are more typical irons. So, whatever is there in the kerosene to booze electrons, and get into positive irons, then these electrons, and cations are accelerated in both the directions by the virtue of the electric field. So, for example, cations is the which are produced let us say positive irons which have produced would rush towards the tools, and the electrons which are there they would try to rush towards the anode side to the work piece side, because of obvious the differences in the nature of the two surfaces in terms of the charge they contain. So, due to the electric field to the electrons are accelerated toward the anode, and because of this acceleration process there is a change in their energy.

So, because of this the overall electron energy increases, and increased energy delivered on a local surface will ultimately discharge the material which is there on the surface, but before reaching the surface, there is a tendency of electrons to create more electrons, and irons. So, if suppose some electrons are emanating from just about to this part of the surface right here. So, the electrons emanated just about here in the part of this surface indicating here in the tool, and it faces some the dielectric field creates break down, and creates positive charge creates additional electrons this electron again which created also get accelerated.

So, these are the secondary electrons. So, there is one kind of electrons being emanated which is primary electron, and the secondary electron which is generated inside the iron column. So, the generated electrons will produce further generated electrons. So, it is a large process. So, it is a sort of chain reaction, and therefore, ultimately, and narrow column ionized dielectric fluid molecules, and this established between both the spots which is corresponding to this location a, and on both electrodes, and these are responsible for the spark, because the column which is created is high ironic in nature shown by the shaded area, and they would give a way to the discharge of electrons from one surface to other. So, it is basically avalanche of electrons due to already existing high conductivity of the positive iron column which we call a spark.

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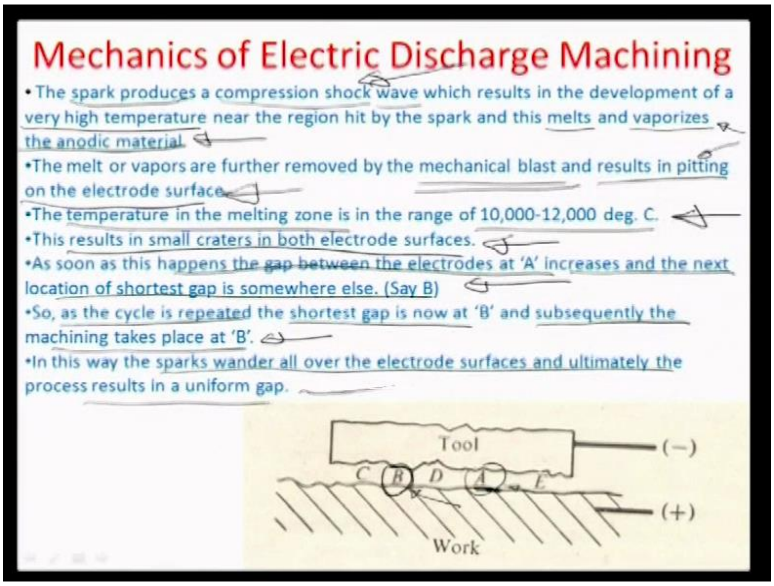

So, let us look at what would happen after this spark is generated. So, as this spark is produced it actually results in a very high movement rate of portional velocity let me just example a small situation. For example, in your you may have been used to the idea why the light bulb glows even if you have switched on ah a electrical switch which is quite far away from the bulb almost to the speed of light. So, so what happens that there is a electrons way which is actually the energy of the electrons which moves very fast through that conductor which has a of electrons.

The bulk of electrons, and it is the way of property of that electrons which gets transmitted as the response that you are see on the light bulb. So, basically it is not the electrons that are getting physically transported, but it is a energy of those electros which is getting transported from very high distance toward the source. So, here also the same thing is happing there is a slight motion towards the emanate of the electorate emanated electrons very near the tool surface, and they would generate motions of other electrons created as secondary electros in the iron column, and it is the motion which is transferring on to all the way across the iron colon to the work piece surface. So, this motion is. So, instanced that it is essentially acts as a compression focus of the medium, which is the dielectric fluid which has been now in that iron column having different compression, and and this particularly on the tools surface, because of the work piece surface, because of high electron pressure has a compressed zone oh which travels almost more than the speed of a sound in the medium produces in the shock wave.

So, this compression shock wave is responsible for creating a huge amount of thermal energy in the medium which distracts. So, the obvious conclusion that would come is that once this depression shock wave is generated near the the surface in question it results a very high temperature, because the energy has to somehow be converted only means of conversion of energy there is thermal, because there is no other means which is available. So, it will immediately rise the temperature of the material across which this shock wave has come, and that generates the sometimes the melt tool of the materials sometimes it is also.

So, hot and so full of energy that it a part of this therefore, there is melt, and actions on the material, because of that now the compression shock wave were comes under very high velocity, and it is almost always followed by a mechanical blast. So, the electron pressure which is been developed at the surface is kind of leading the movement of the material which is there in the dielectric column, and electron motion, because of the small size of the electron is always very fast, and very high velocity, and the remaining part of the column is not able to keep space with the electrons motions, because of its own components associated with it.

So, it generally arises that later point of time before the electrons have created the affect of the surface. So, electrons have virtue of the compression shock wave created extremely high region which is melted, and the material, and the mechanical blast just following that electrons which comes after few units of time after the the instant where the temperature gone up, and it is able to remove the melt tool or sometimes whatever wafer is to that tool, and it basically removes it into the dielectric fluid this results in the pitting action on the surface of the electrons. So, mechanical blast, because which which follows the electrons pressure, and result in pitting action is the basic removal mechanism of materials in these discharges.

So, some facts, and figures about this process are that the temperature on the melting zone sometimes goes in the range about ten thousand to twelve thousand degree celsius, and this may result in small in both the electro surfaces, and as soon as this happens the gap between the electrode, and a increases, and the next location of the shortest gap is somewhere else say some other gap b here. So, a has already the has happened here in the work piece and. So, the next point of closest reaches the point b. So, as the kept on repeating the shortest gap now at b, and subsequently the machining takes place at b. So, after a the next round of machining happens at b.

So, if you consider this this phenomena to a regular process it keeps on repeating over the whole surface, and eventually results in dancing spark over the whole surface, because wherever there is a close proximity between the two surfaces the spark is place there. So, it is a high frequency spark which kind walks over the whole surface based that difference in terms of facing of both the surfaces. So, that mechanics of material removal in the e c m process. So, today we are at the end of this lecture, but, then in next subsequent lecture we will talk little more on what is the material removal mechanism how can be predict with the modern mathematical model the removal mechanism, and then will also look at some other aspects which are very important in e c m design like. What kind of feeding surface can be designed for any e c m systems. So, that this ah electron emanation process can be self sustained one and so on.

Thank you.