Microsystem Fabrication with Advance manufacturing Techniques
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Lecture – 25

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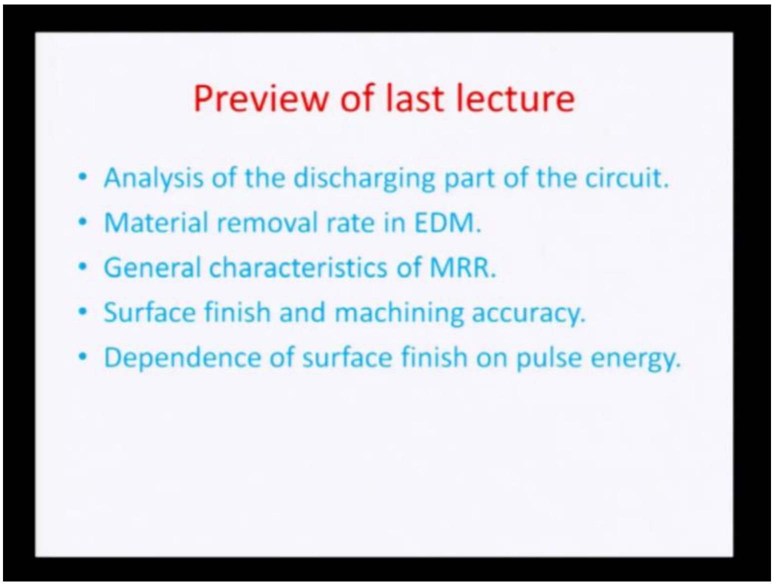

Hello and welcome back to this lecture, 25 on micro system fabrication by advanced manufacturing processes a quick recap of what we did in the last lecture. We talked about the analysis of discharging part of the r c relaxation circuit we also discussed about the material removal rate in E D M a pa particularly in case of mild steel there is an established empirical relationship depending on the amount of power which is given in kilowatts, and the about the material removal, and millimeter cube per minute. We also talked about several general characteristics trends of the material removal rate with respect various circuit parameters like resistance capacitance the total discharge current. So on. So, far spark gap we talked about Surface finish, and machining accuracy. And then finally, we had a close discussion about the dependence of surface finish on pulse energy of the e d m system.

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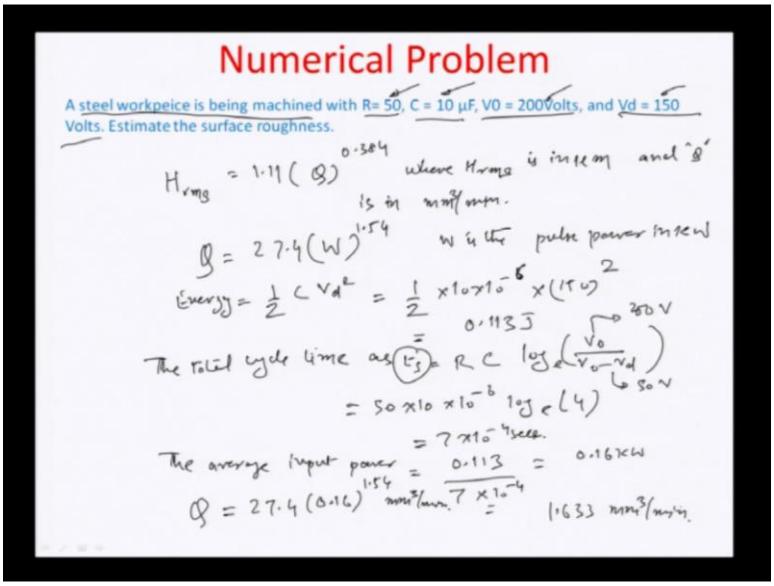

So, today we will just try to go ahead, and try to look at an estimation numerical estimation of the surface roughness in a particular situation. Now this problem here represents such a situation here, where a steel work piece is being machined, and the circuit parameters are given to be resistance r equal to 50 ohms capacitance c is equal to 10 microfarads, and total operating voltage of 200 volts the discharge voltage of 150 volts, and you have to estimate the surface roughness, which is also the h r m s value, and if you may recall from the previous lecture the h r m s is represented as 1.11 q to the power of zero.384, where the Hrms is in microns, and Q is in m m cube per minute the energy here which is delivered is actually dependent on this resistance, and capacitance, and also the various parameters like operating voltage, and discharge voltage.

And we do have in case of particularly mild steel very active relationship to derive the q empirically as 27.4 w to the power of 1.54 where w is the power the pulse power in kilowatts, and how we calculate w is by looking at the energy which is half c v d square, and capacitance c is 10 microfarads 10 tend to the power of minus 6, and discharge voltage is 150. So, this comes out to be equal to zero.113 joules the total cycle time can be calculated as t c which is actually equal to the resistance times capacitance R C log of v 0 by v 0 minus v d, and this particular case this happens to be 200 volts, and this comes out to be 50 volts and. So, the total time cycle or cycle time is represented as 50 times of 10 10 to the power of minus 6 log, and this is to the base e log to the base e of four two hundred by fifty, and this comes out to be 7 10 to the power of minus 4 seconds or around 700 micro seconds the average input power. So, energy per unit time can be represented as 0.113 divided by 7 10 to the power of minus 4 that is 0.16 kilowatts, and the total q material removal rate comes out to be 27.4 times of 0.16 to the power of 1.54 m m cube per minute, and this equals 1.633 m m cube per minute.

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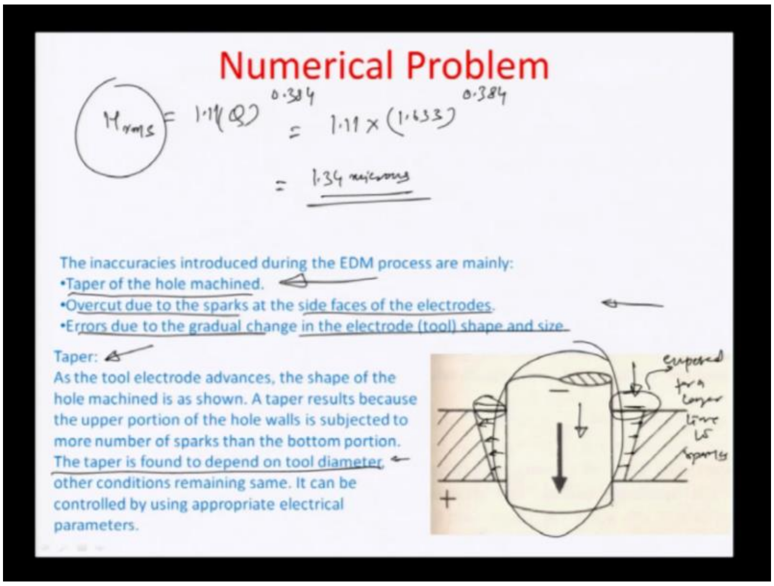

And based on that subsequently we can find out the surface finish by using the expression h r m s equals 1.11 q to the power of 0.384 this is 1.11 1.633 to the power of 0.384 becomes 1.34 microns. So, essentially this is how the h r m s value comes out to be equal to now there are few aspects. So, which need to be mentioned here, and those are about the inaccuracies while considering the EDM process or let would a shear machining process. So, the main kind of problems which come in an e d m process are, because of the amount the difference in the time that a particular whole various portions or various portions on the wall of a particular whole is expose to in terms of receiving the sparks from the e d m machine.

So, the taper of the machined hole in an e d m is the major inaccuracy a due to which you have to suitably designed the electrode sometimes. So, that it compensates for this taper, and you can have a straight cut there are the problems like over cuts due to sparks at the side faces of the electrodes, and then there are errors due to the gradual change in the electrode tool shape, and size. So, principally these are the three categories into which you can determine or you classify all the in inaccuracies produced e d m process.

So, let us look at the details of how a taper would be produced. So, as we know that the electrode this electrode here advances towards the work piece the shape of the machined hole is shown here, and you if you look you know when the electrode is coming here in the top portion write about this portion the spark exposer to the surface starts immediately, and then, because of which there is local melting, and then material which goes away, but as the tool proceeds town words slowly this sparks exposer increases to the side walls, but the tendency of the spark to formulate near the surfaces still remaining. So, the surface gets exposed for a longer time to sparks causing a a greater diameter of the surface hole in comparison to the hole at a certain depth. So, it is found to depend on the tool diameter of course, and what you can do is you can either appropriately Insulate the tool or you can create a suitable condition by you know changing the electrical parameters. So, that this problem of tapering can be minimized.

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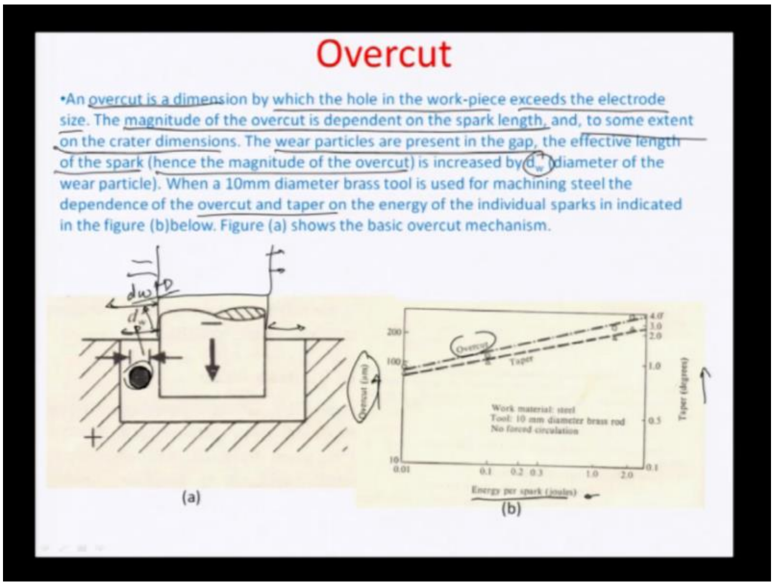

So, that is one aspect causing an inaccuracy the other is an overcut which typically means that there is always some kind of a extra size of the hole in comparison to the tool diameter. So, typically an overcut is a dimension by which the hole in the work piece exceeds the electrode size the magnitude of the overcut is dependent on the spark length, and to some extent on the crater dimensions supposing there are wear particles, which are present in the gap here like this is a wear particle the effective length of the spark. And hence the magnitude of the overcut is somehow increased by this Wear particle, because if you consider the spark length to be the some you know equal to the overcut in this particular case this spark is facing it is own metal particle which has been removed, and it should get extended by exactly the same diameter. So, from here it goes to here supposing this were d. So, this d plus d w d w is the diameter of the particle. So, this is the perennial problem of taper, and overcut of e d m machines, and again this really when the with the tool is approaching this point the only this zone is being exposed, but as the tool goes inside the side zones are being exposed.

So, this can be controlled in a way in a limited vanner by again side insulating the tools. So, that there is no extra spark length which is formulated, and know extra Overcut with this formulated. So, if you look at the energy verses taper in most of these tools, and as a matter fact even the energy verses the overcut as you can see that if the spark energy is increased both the overcut as well as the taper they vary if you look at on with overcut size spark energy is more the overcut is linearly increasing as you can see, and on the other hand if spark energy is more the the taper also is substantially increasing.

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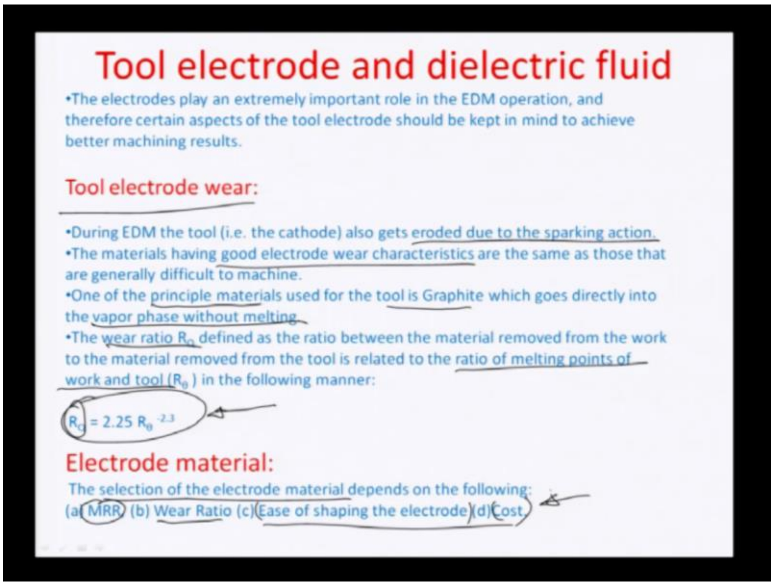

So, all these defects or all these abrasions are really related to the spark energy in jules of that that that the e d m process has to offer let us also talk a little bit about tool, and electrode that the tool electrode, and the dielectric fluid as is obvious that electrodes play a very important role in determining how successful an e d m operation could be, and how what what are the different electrical parameters of an electrode also somehow matters for the formulation, and generation of the spark. So, the material selection for the electrode is very important aspect in any e d m process given a particular material combination on the tool on the work piece, the other thing which is of significant importance's the tool wear the tool electrode wear, and that is, because off course there is a sparking action going on continuously between the work piece, and tool.

So, there is a erosion which happens due to this sparking action both at the work piece which is the for all the m r r or the machining removal material removal rate, and the electrode side where actually the electrode gets melted, because of repeated sparking. So, a material should be chosen which has relatively good electrode wear characteristic meaning there by that we would machines the the work piece, but done the electrode wear is minimum. So, one of the principle materials that are that is used for a the tool is graphite it goes directly in to the vapor phase without any melting, and you can define this wear ratio Rq as 2.25 r theta to the pair of minus 2.3 is again an empirical relationship were the r theta is really the ratio of the melting points of the work, and the tool, and R q is the wear ratio. So, if you have a good choice, and the material of the tool has a melting point which is greater than that of the work piece the r q the wear ratio automatically improves, and vice a versa.

So, the selection criterias of the electrode material really depends on what kind of material removal rate you need to use what the tool wear ratio that you are targeting, and also what is the ease of machining these electrodes, because you can have the exact negative shape what you are going to machine on a plate, and also the cost has to be kept in mind of the particular electrode in question.

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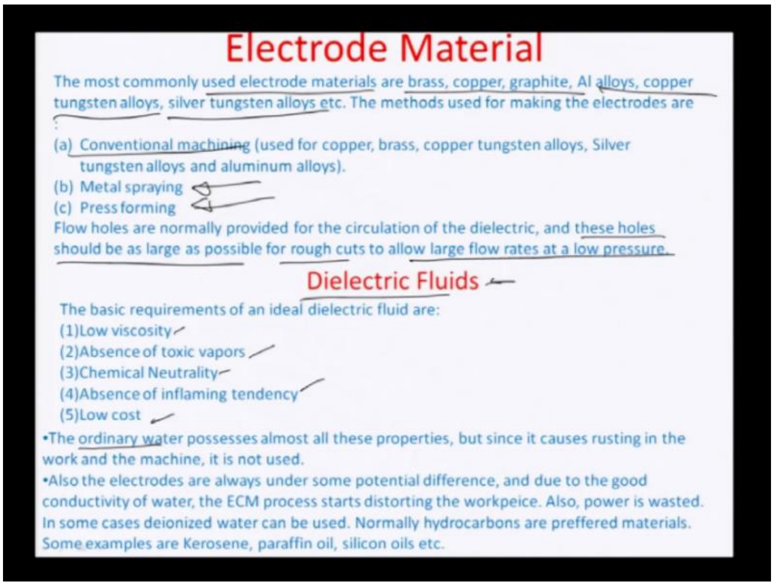

So, most of the commonly used electrode material that are used as brass copper graphite aluminum alloys copper tungsten alloys silver tungsten alloys etcetera, the methods that are used for making the electrodes are either just normal conventional machining, and some time micro machining with great precision, and accuracy this is become a really major aspect on some of the example problems will take of later on in the mems area are really using e d m towards the micro machining, you can also use metal spraying for developing the electrodes or press forming is operations for these electrode materials normally you prefer the e d m electrode to have circulation of the flue it to be in the near vicinity, because as the circulation increases the material removal rate enhances we have talked about this many times.

Therefore, it is pertinent to mention that flow holes need to be design within the electrode which will support this circulation, and make it easier particularly considering the fact that the electrode work piece gap is minimum in e d m operations. So, there are these holes which should be as large as possible for rough cuts, and allow large flow rates at low pressures without much bending. So, that they are does not occur any sort of depreciation or damage to tool surface, and at the same time it allows for enough circulation in the e d m time. So, basic dielectric fluids which are used for e d m have the requirements of low viscosity of course

So, that they can flow easily they should have the absence of toxic vapors, because otherwise the operator gets exposed chemically they should be neutrality without any. So, that even if they get decomposed, there is no a particular deposition which would take place on the electrodes or very minimalistic deformation which deposition which would take place at the electrodes should have the absence of inflaming tendency of this fluids it should not burn up or the, then should be low cost. So, typically ordinary water on sometimes mineral oil are used mostly for e d m fluids, and what is also important is that ah de the the fluid that you are using should have a relatively higher dielectric constant. So, that it can support the the respective potential reference between the tool, and the work piece. So, that it can lead to a sparking condition. So, with this I thing the e d m section is more or less covered now we will start a very new, and interesting topic of e b machining following this.

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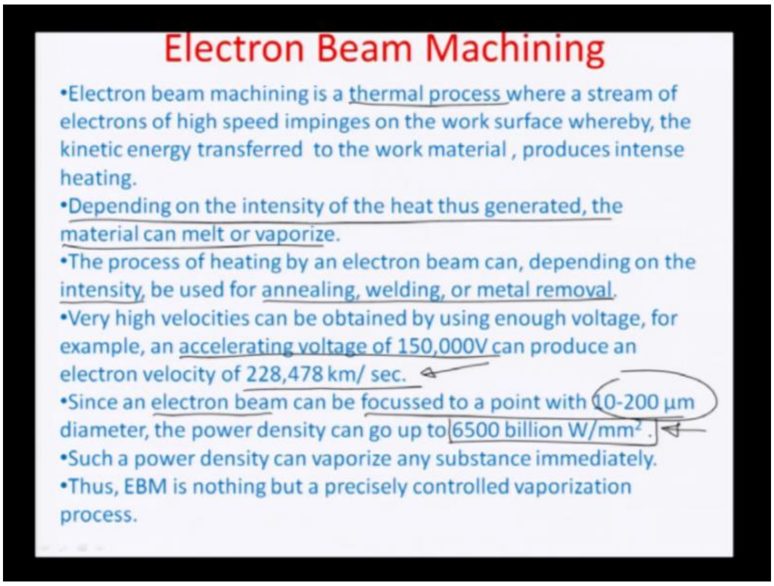

So, in electron beam machining, as you know it s a thermal process where a stream of electrons is impinged on to a work surface, and that is impinged at a very velocity thereby transferring all the kinetic energy that this electrons have or they processed on to the work surface. So, it is basically a sought of integration of electrons with the matter which leads to the vibration energy of the matter itself, and does increasing the localized temperature to a level, where the material the atoms the material would come off as atom in in a atom by atom manner. So, depending on the intensity of the heat generated the material can melt or vaporize, and the process of heating by an electron beam can depend really on the intensity of the beam, and can be use of various of applications like may be annealing may be welding or metal removal by delivering suitable heat content in every case. So, just some facts, and figures about the electron beam machining typically you have to have very high velocities of the electrons coming out from the source.

And you know the kind of velocities that those electrons would have could range in several tens of thousands kilo meters per second, and if we you apply suitably high accelerating voltage of to to the to the to the electrons and. So, type if you look at facts, and figures if an accelerating voltage of above hundred, and fifty kilo volts is applied it can produce a fast electron as fast as above two hundred twenty eight thousand four hundred, and seventy eight kilo meters per second which is very fast and. So, you can imagine that this kind of speeds important on to the electrons would lead to what kind of latus vibrations as the electrons the material surface, and that is one of the principle reasons why things can or vaporized sometimes directly, because of the high amount of kinetic energy it is not one electrons.

It is a beam of electrons which is being a focus to on to a single spot where machining is to be done. So, typically if you look at again some of the values if a electron beam like this with above 228,478 kilo meter per second velocity of individual electrons can be focused to a point which is about 10 to 200 micro meters in size you can go to delivering a power density as high as 6500 billion watts mili meter square. So, this is how much you know energy can be delivered really in a very focused manner on to a surface now this kind of power it if applied to the latus structure or the material as search can simply vaporized the material substantially.

So, it just directly sub limits it goes in to the vapor stay, and if you if you raster the e b m over the surface typically there is a tendency of the the machine into be precisely control based on wherever the beam hits the material and. So, as you can really super focus, and narrow down the beam to a small spot that is elusion at which you can do this increases one of the reasons why e b m is a preferred modality, and most of the micro machining or nano machining processes, because of the precision accuracy, and the resolution limit of the system these days e b m lithography which is a very modern process, and will be describing in some of the lectures later is essentially using same principle of an accelerated beam super focus on to a small spot, and it creates enough damage to the material, and the the are beam sensitive like may be p m m a for philomathlic metacrilic where such interaction would result in material coming off on the surface or in a selective manner. So, you can actually imprent with this technique features as a small as several tens of nano meters space pie equal distances. So, that is the resolution at which you can write going to the fast, and the small spot size, and scanning sped respectively.

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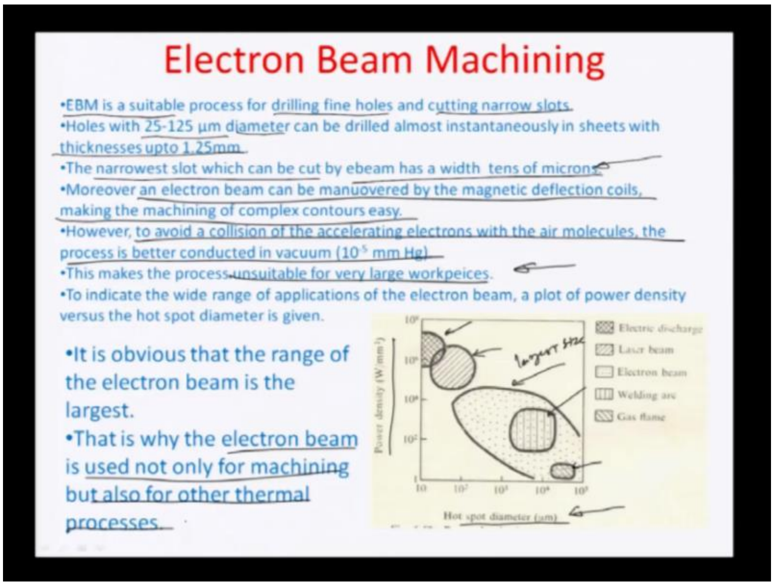

So, if we look at some of the dimensions of features that abeam m is suitable to use. So, typically e b e b m has been use for drilling of fine holes cutting narrow slots holes as small as 25 to 125 microns diameter, and this limit has I think further gone down depending on morning technology that is being increasingly use to super focus the beam. It can also be use for drilling thicknesses up to above 1.25 millimeters. So, really high aspect ratio features instructors can be drilled in metals using this technique. So, the narrowest slot which can be cut by abeam has a a width tens of microns in this, I think we have discuss before, and an electron beam can be maneuvered by typically magnetic deflection coils making the machining of complex contours easy.

So, it all becomes a matter of programming the topology of a surface an the beam direction direction can be controlled by suitably varying magnetic field is space. So, you have lot more flexibility to raster the beam on complex shapes, and features as well which may not be the case in some of the conventional machining were metal to metal contact is is needed. So, one has to; however, be careful of one small factor that these electron beams are high energy an. So, typically they should not come in direct collision with air mollusks which might create ionization, and lot of undesirable effects which might change the resolution greatly. So, typically, and only limitation that the e b m system has to offer is that are done in high v a c high vacum columns, and the work piece size has to be limited, because of the associated complexity of creating vacum to the level of almost no air I mean probably ten to the power of minus six or minus seven fresher were minimum amount of is permissible.

So, typically you do these in vacuum columns which limits the size, and it the process becomes on suitable for large work pieces, and if you look at the way that the different applications can be grouped as a plot of power density delivered to the surface with respect to the hot spot diameter you can see that for the e b m machining typically the combination has the largest size meaning thereby that it works for a lot of hot spot diameters with a wide ranging power density in what per millimeter square on the other machining processes are quite limited as you can see here let discharge laser beam. In fact, welding are gas flame, so on so far were the e b m by enlarge has the largest range of the different values of power density, and hot spot diameters it is obvious that the electron beam is there for one of the most preferred thermal processes for all kind machining activities in comparison to some of these others form where associated sparks or high power optical beams are being used.

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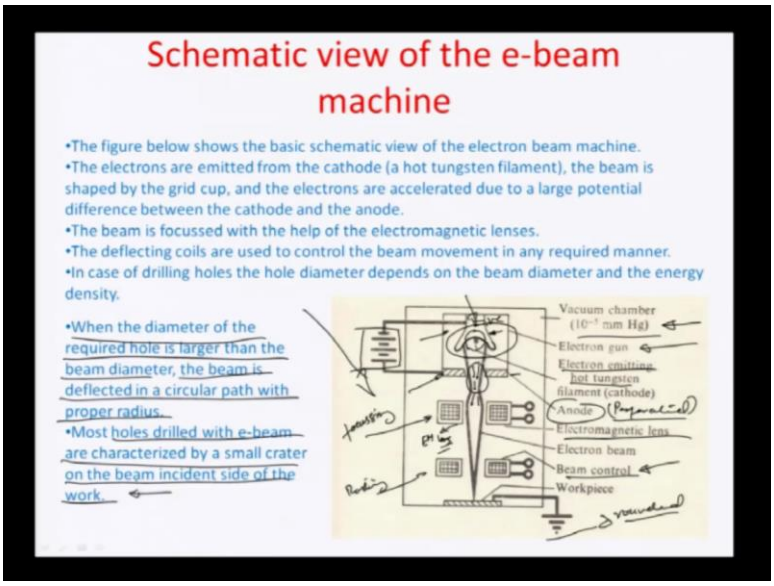

So, this typically shows the layout schematic layout of a beam column with generates the electron beam, and as you can see here the beam column has several parts is typically stood in a vacuum chamber which has a 10 to the power of minus 5 or minus 6 millimeter mercury vacuum level there is an electron gun which operates on the principle of theorization meaning thereby that of this gun is heated on it is a surface there is a filament, and this is also the cathode which is electron rich you can see a the way this power supplies position making this the negative electron and. So, there are huge amount of electrons which are existing in this particular region here of the electrode there is a hot tungsten filament which heats this cathode. So, that it starts thermanising the material, and electrons come off by virtue of termini chemisions of the surface, and then there is a driving anode here which is also perforated in nature. So, this is perforated anode, and the is that as an most of the e b m columns even used for scanning electron or thermaling microscope processes.

The the electron does generated out of this cathode are pumped through the voltage which exist between this this anode, and the cathode. So, the potential difference existing here is responsible for impart in kinetic energy on to the therminically electrons, and as they go into space they also get squished, because of the shape of the emitter here, and in a way they are further squished by using electromagnetic lenses, and there are two set of lenses one for focusing, and you can see here, and the other set lengths for rastering the beam whereby just wearing magnetic field you can do beam control on the work piece a work piece is typically grounded.

So, that it is by virtue of it is state of electrostatic potential also captures maximum electrons which are generated by the beam. So, the grid shaped cup here is very important for focusing the primary focusing of the beam which occurs in this particular region which ensures that this beam kind of get's into the narrow gap of electromagnetic lens as show here e m lens. So, when the diameter of the required hole is larger than the beam diameter a typically you take the beam around in a circular path by changing the beam control, and this will result in a much wider area of rastering, and scanning on the surface resulting in machining. So, most holes drilled with e beam are though characterized by small crater on the bean incident side of the work piece.

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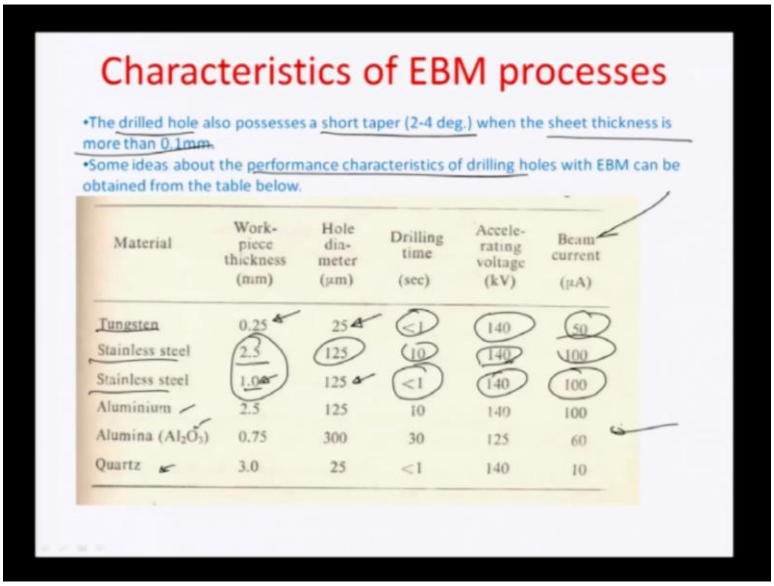

So, that is how a e beam system operates, and generates the beam some characteristics typical of the e beam processes are the drill holes that are mostly achieved by using e beam a machining processes have a short taper of 2 to 4 degrees, and particularly this. So, when the sheet thicknesses more than 0.1 millimeters, and the taper in this process comes by the fact that again the same principle that as the beam hits the surface, and goes below are clause below the surface that is still tendency, because the the surfaces in ground potential of the electrons to get reflected, and captured by the walls, and therefore, as long as the drilling processes continuing.

And the material comes off in a from you know in this in this cavity which is being formulated the sides of the cavity are thereby also equally exposed, and that results in some kind of continuous removal on the sides, and they are more exposed in comparison to the bottom the very bottom and. So, therefore, the slide taper. So, some ideas about the performance characteristics of this drilling holes can be obtained this table here for example, if the material that your machining tungsten work piece on the sheet thickness may be about let say above 250 microns a hole diameter of 25 microns need to be created. So, typical parameters of operation include drilling time of less than above one second accelerating voltage of 140 kilo volts, and a beam current of 50 micron pairs if it stainless steel material stainless steel you have a 2.5 millimeter work piece thickness a with the hole diameter of 125.

Microns in the drilling time is over 10 times more above 10 seconds, and that is using an accelerating voltage of same border 140, and a beam current which is double about 100 micro amps similarly for stainless steel the thickness changes to 1 millimeter hole diameter 125, and the drilling time is still less here less than one second a using similar beam parameters 140 kilovolt accelerating voltage is an hundred beam current hundred micro amp beam current. So, in a way this work piece thickness defines a lot of machining time can be seen here some other materials are for example, aluminum alumina, and quartz, and their respective times have been mentioned here in this particular table.

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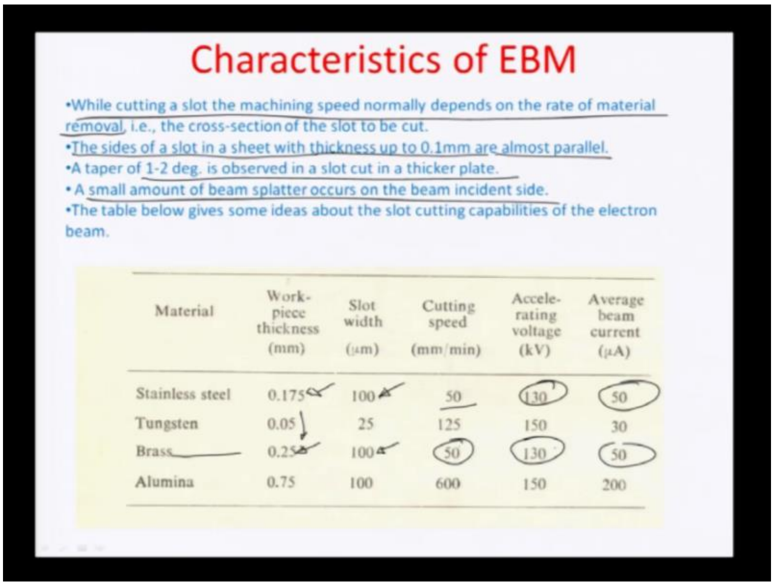

So, that is how your placed as for as the e beam process parameters go some other characteristics of e beam. So, while cutting a slot the machining speed should intuitively depend on the rate of material removal that you need, and also this for response to nothing, but the cross section that you want to actually machine or cross section of the slot that you want to cut or remove on the material.

So, the sides of a slot in a sheet with thickness up to 0.1 millimeter are almost parallel a taper of about 1 to 2 degree is observed in a slot cut in a thicker plate smaller amount of beam splatter occurs on the beam incident side in the work piece, and some of these values are represented here in the table you can see that corresponding to about hundred, and seventy five microns thickness slot width of above hundred microns you can get a citing speed of above fifty millimeters per minute with an accelerating voltage of 130 k v an a average beam current of 50 micron, and this changes as you go between stainless steel tungsten brass alumina brass being a softer material you can see the same kind of cutting speed can be obtained for slightly higher thickness of the work piece with similar accelerating voltages, and average beam current which is intuitively quite feasible.

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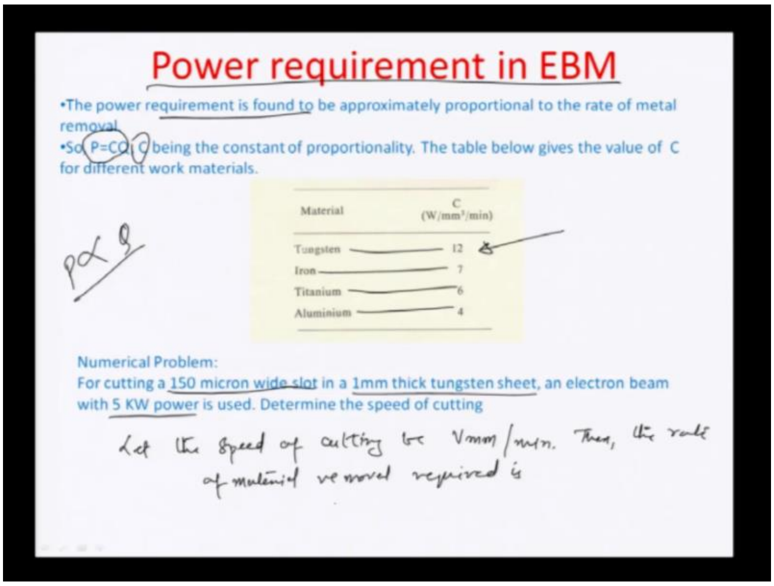

So, if we talk about the power requirement in a e beam of the requirement is found to be approximately proportional to the rate of material removal. So, if Q is the material removal, then this power needed is proportional to q, and the constant of proportional decease has been mentioned here in terms of power in watts per unit material removal rate in millimeter cube per minutes c. So, for tungsten to iron to titanium to aluminum you can see this different values of c as reported in this table a let us to a quick problem to have an idea of the numerical values of the various power requirements which are increasingly felt in e beam. So, let us say we want to cut a 150 micron wide slot which is about on a 1 mm thick tungsten sheet using an electron beam with 5 kilowatt power. So, determine the cutting speed in this particular case let us see how the cutting speed can be found.

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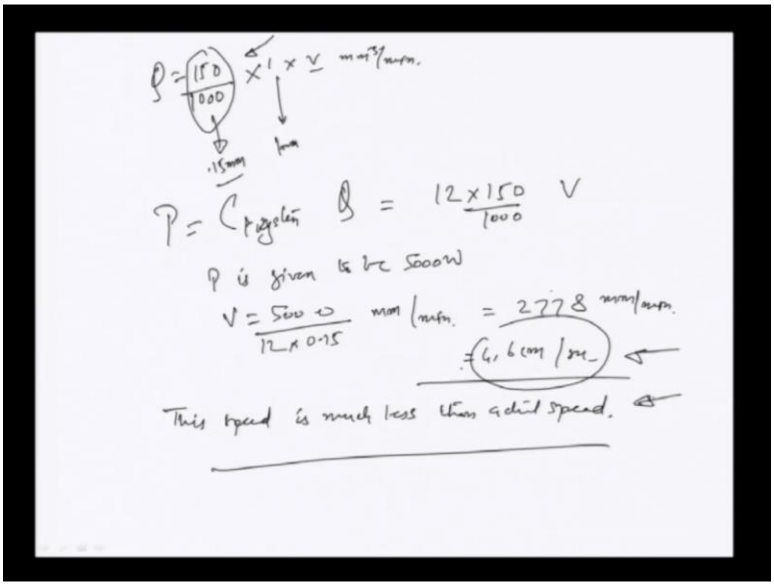

So, let the speed of cutting we assume to be v millimeters per minute, then the rate of material removal required is given by q equal to 150 by 1000 times of 1 v millimeter cube per minute you know that in the slot is about 15 m m wide an about 1 m m thick. So, this volume is coming from cross section times of speed of the beam per minute time gives you hou many m m cube per minute you want to remove and. So, p in this case can be represented as c tungsten times of q which 12 times of 150 by 1000 volts, and p is given to be 5000 watts v comes out to be equal to 5000 by 12 into 0.15 millimeter per minute that is 2778 millimeter per minute of 4.6 centimeter per second which is quite appreciable velocity.

So, this is the velocity at which the beam should raster on the surface for creating a cut about 150 microns, and one m m thick. So, this p though is much less than actual speed, and one of the reasons why the actual speed is more is that there is a huge amount of thermal dissipation from the cutting zone to the areas at joint to it and. So, that factor is not being accounted for in this particular simplistic mode of p equal to c q material removal rate. So, let us now understand a little bit of the techniques of how what are events the sequence of events in which the materials starts getting from the surface as being hit pone by an e beam.

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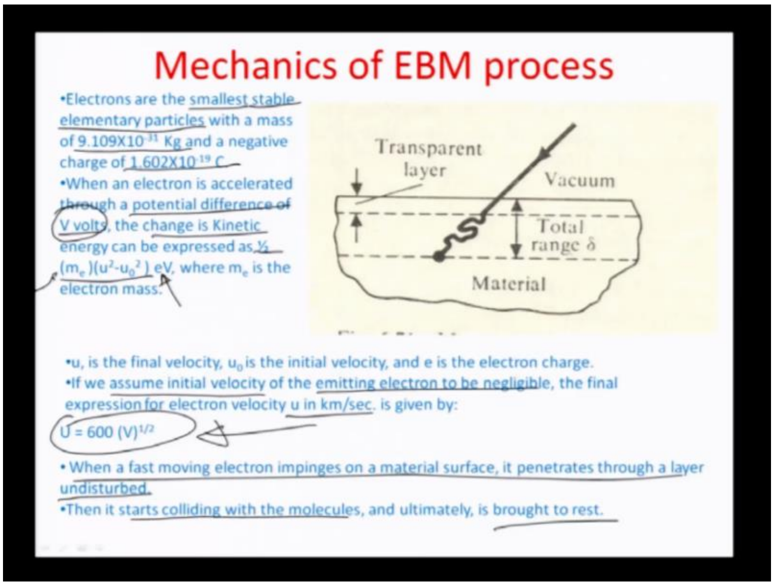

Some of facts, and figures that probably we all realize are that the electrons freely are the the sought very stable small elementary particles with charges in the range of 1.602 10 to the power of minus minus nineteen culan a it contains negative charge, and on the amount of mass that it has is typically 9.109 10 to the power minus 31 kg. Now such an electron is accelerated through a potential difference let say v volts the change in kinetic energy can be expressed as half into electron mass nine point one ten to the power minus thirty one times of e square minus u zero square, and this is in e v electron volts right where m e is the electron mass. So, typically we already have discuss this before that the amount of velocity is that the electrons hit upon is a huge it is in the range of about hundred of thousands of kilometers per second with which the electrons start moving, because of these accelerating potential, and the thermanic effect.

So, it has been increasingly found that as the electron goes very near to the surface of material there is a you know the material is not able to register, and immediate effect on the electron striking, because by virtual of the electron size being very small there is always the formation of something called a beam transparent layer on the top of the surface. So, the actual kinetic energy deliverance of the electron beam happens within some particular depth from the surface, and this area is actually called the effected zone in the e beam crosses e beam machining process, and this beam transparent layer is you can think of it as a layer which you know the electron velocity through which goes undetected particularly, because it is it is. So, fast, and it is very rapidly moving, and very small the layer is not able to get excited to the vibrations are not able to really get started the movement the the electron passes through them. So, therefore, when a fast moving electron impinges on a material it penetrates through a layer undisturbed before it is starts colliding with the molecules ultimately brought to rest.

So, what essentially you are doing is that this half m v square energy is been transferred on to wherever the electron is finally, hitting upon, and wherever the electron is finally, coming to a rest. So, if you assume in the initial velocity of the emitting electron to be negligible the final expression of the electron velocity kilo meters per second can be expressed by this term here where it is 600 times v to the power of half, where the v is basically the potential difference across which the electron is being moved, and this is the really abeam parameter. So, if it is a hundred, and fifty k v a kilo kilo kilo volt through which it moves, then this v corresponds to hundred, and fifty thousand value. So, it is a very high value, and that is how the u is determined for the electrons in kilo meters per second.

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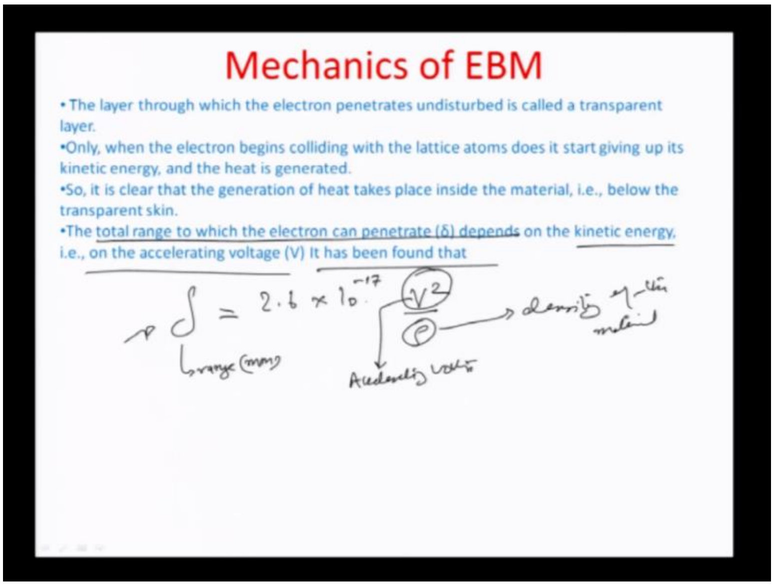

So, electron finally, after the beam transparent layer is cross to collides with lattice atoms, and imparts vibrations on to these atoms due to which there is a increase in the thermal energy, because of random lattice vibrations occurring in a certain region. So, this; however, happens beneath the skin or the upper portion of the also called the beam transparent layer. So, there is always a skin which is developed in the machining zone below which the hole thermal energy is generated by conversion from kinetic to thermal. So, the total range to which such an electron can penetrate if you call the delta. So, it typically depends on what is the kinetic energy what is the accelerating voltage etc, and imperially it has been really found that the delta the beam penetration dept can be related to the voltage by the equation 2.6 10 to the power of minus 17 square of e by p row where this delta is the penetration range in millimeters v is the volt so voltage. So, it this is acceleration voltage, and row is the density of the material. So, that is how you can correlate. So, it really varies is the square of the acceleration voltage v.

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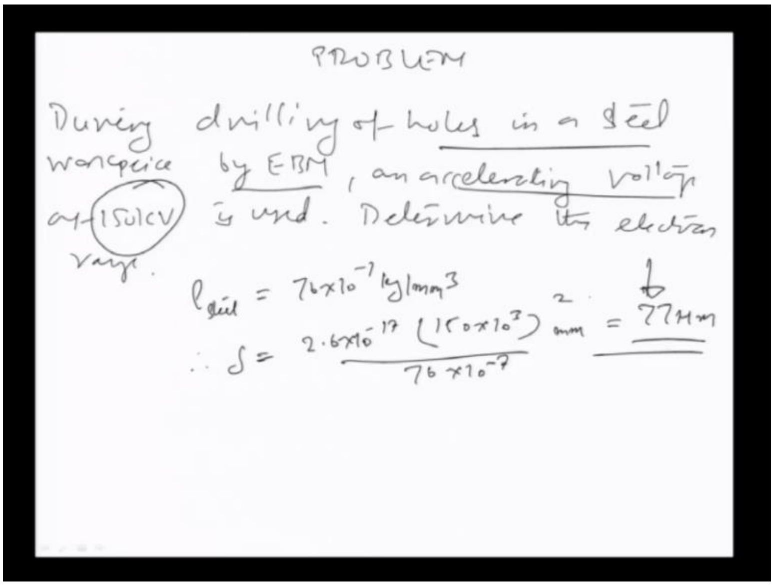

So, let us look at problem example here. So, during drilling of holes in a steel work piece by e b m we have hit upon an accelerating voltage of hundred k fifty k v. So, we determine what is arrange of depth just to give you an idea of the value of this transparent layer how small it is. So, let us look at the density of steel here density of steel is equal to 7 to 6 10 to the power of minus 7 k g per millimeter cube, and delta by that equation becomes 2.6 10 to the power of minus 17, and the square of which is 150 times 10 to the power 350 volts kilovolts square of that times divided by 7 to 6 10 to the power of minus 7.

So, this only comes on this is an m m millimeters this comes out to be about 77 microns. So, that is how small this skin is the skin which is not effect it as the electron beam goes. So, transparent layer is about close to tens of microns which is formulated by an accelerating voltage of hundred, and fifty k v off course if the accelerating voltage is changed, then this delta value will increase further, and depending on what they acceleration voltages can be it can go up probably thousand k v also this can go up to about hundred microns hundred to hundred fifty microns. So, that is how much this a penetration depth can go up to a in. So, in the interest of time.

We have to close todays lecture, but then in the next lecture I would like to talk about the thermal modeling part associated with the e beam, and try to develop a analysis of how this local temperature raise would lead to melting of the materials, and try to relate them to the material properties for getting a good understanding of the machining processes.

Thank you.