**Microsystem Fabrication with Advance Manufacturing Techniques**
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**Lecture – 26**

Hello and welcome back to this microsystem fabrication by advanced manufacturing processes lecture 26 quick recap of what we did in the last lecture talked about surface roughness of e d m operations electro discharging machining operations.

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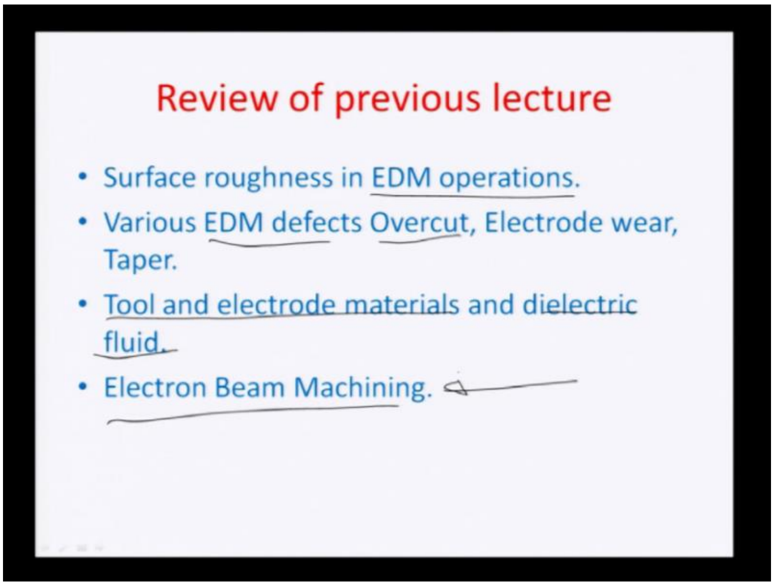


We also talked about the various e d m defects like over cut electrode wear, and taper, and due to the unequal exposure of the work p is to these sparks coming from the tool electrode we also talked about tool, and electrode materials, and dielectric fluid particularly the tool material should be chosen in a manner. So, that wear is minimum, and dielectric fluid which actually is is circulated in the space between the tool electrode in the work piece, and should have typically high breakdown consent there can be water based or oil based fluids which are used, and then we started talking about electron beam machining, and the way that this is the resolution of a system can be improved or enhanced by using a super focused high energy electron beam. So, we just go back that, and try to recap some of the things regarding electron beam machining. So, in this e b m process there is a electron beam which is created through a thermalization effect using a grid cup shaped electrode charged at negative voltage, and then subsequently there is a perforated anode which is used to full of the electrons, and focus them. So, subsequently with the magnetic field. So, that it can be focused to a very small spot size there are difficuly typically two magnetic fields which are created the first lens system which is creating this electromagnetic field these used to focus, and make the beam narrower, and the second is used for rastaring the beam over the surface, and basically the relative change of the beam with respect to the surface according to guided by the different shapes or sizes that the beam has to incorporate on to the work be surface is controlled by the second magnetic lens.

So, there are certain disadvantages that we discussed about e b m one of the major short coming of the processes that it is a high vac high vacuum process meaning there by that. So, state sizes are limited, because a typically these vacuums are established in columns, and the other issue about e beam machining is that it is it is really high resolution process. So, that is an advantage for the e beam machining. So, you know you can do a load of writing a very small resolution now a days the the e b machining is done on nano scale on to the nano scale by making a feature size of as smaller as about ten nano meters separated by equal spacing, and these process is known as e b m lithography were you can write it on resist surface. So, let us actually we look at some of the mechanics associated with the e b m process.

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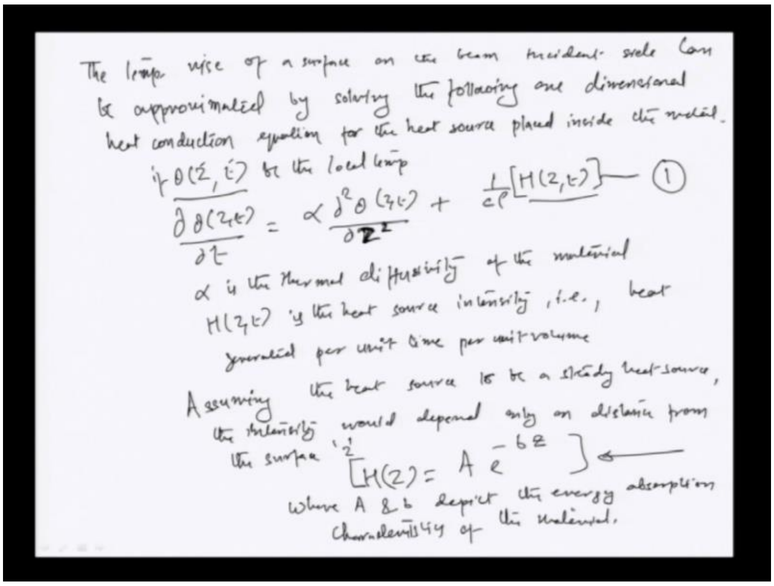


So, let us say the temperature raise of a surface on the beam incident side can be approximately approximated by solving the following one dimensional heat conduction equation for the heat source placed inside the metal. So, if theta z t b the local temperature at certain depth z from the surface at a certain point of time t, then the dough theta z by dough t comes equal to alpha second space derivative temperature with respect to the depth z square plus one by specific heat capacity time of density of material times of the heat flux h z e t this equation alpha is the thermal diffusivity of the material, and h z e t is the heat source intensity that is heat generated per unit time per unit volume assuming the heat source to be a study one study heat source the intensity, then would depend only on distance from the surface zee. So, we can actually represent this h z equals eight minus let say some constant b times of depth from the surface where a, and b depict the energy absorption characteristics of the material. So, if we use a this heat equation for describing the study state heat source as if the beam has hit on a surface, and it is a cylindrical beam, and the heat conduction across the surface is time invariant.

That means it is study heat flux in to the surface. So, the equation that has been earlier obtained here equation one can be really a written down in terms of can be slightly modified, and written down in terms of this study state heat source and. So, h typically would not depend at time t equal to 0 only on zee, and also corresponding to all other times after zero. So, that is how the p d can be expressed.

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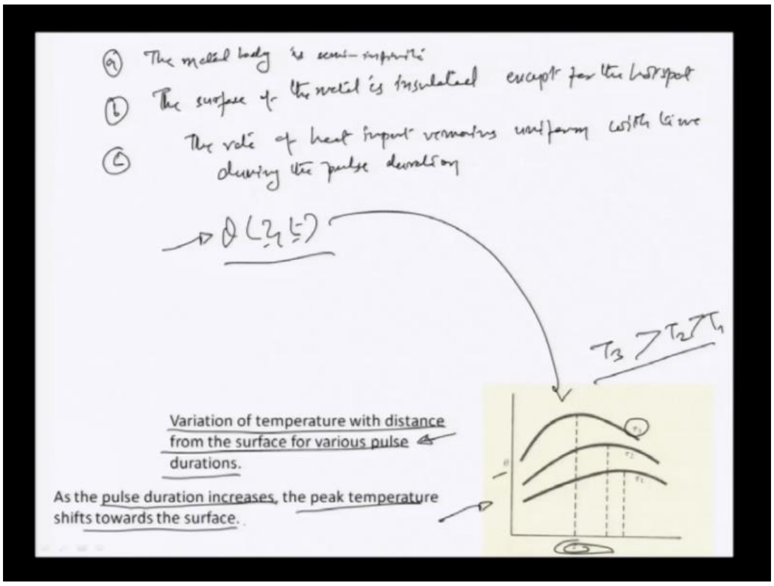


If these p d assuming that the metal body semi infinite in nature the surface of the metal is insulated except for the hot spot, and the rate of heat input remains uniform with time during the pulse duration.

And then if we plot the nature of t theta zee t temperature with respect to the depth from the surface z, and the time t we obtain the plor of theta as indicated here with respect to z here one thing that we can observe very well is that the variation of temperature the from the surface or as the result of the distance from the surface that p d is the function of the various pulse durations of the e beam. So, if the pulses time is greater in this particular case for example, tau three is greater than tau two is greater than t one there is a gradual shift observed of the maximum temperature point towards the surface.

So, as if the beam transparent layer that the electrons seek through while going in to the metal is decreasing, because of a increase in the pulse duration in other words you may think of it physically as there is some kind of a homogeneity of the temperature at the pulse duration is large, and it really achieves a study state and. So, therefore, already the temperature over a certain critical point, and the beam when it comes new on to the surface does not see that much transparent layer that it was supposed to see before, because already it is very heated up, and already there lost of vibration which are happening.

So, in reality the physics of the problem also kind a get replicated by the variation of theta with respect to z as can be seen here. So, there for the as the pulse duration increases the peak temperature shifts towards the surface. So, we would now like to perform a sort of dimensional analysis for also checking the consistency of the the various parameters of cutting with respect of the of the e b m process with respect to the material removal rate using the baking hams pi theorem. So, the first thing of importance is to able to look at what are independent, and dependent parameters in the whole e b m process the e b m machining process.

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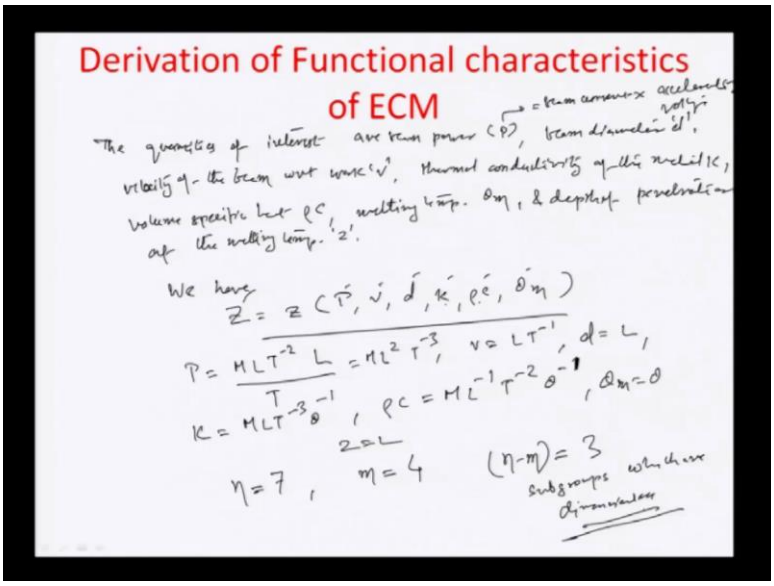


So, let us look at the various quantities of importance here they are beam power, and we already know that this beam power can be written as the beam current times accelerating voltage they are beam diameter velocity of the beam let us call it v thermal conductivity of the metal k here volume specific heat rows as has been used in the earlier term as well melting temperature theta m, and depth of penetration of the melting temperature z. So, we have z is equal to function of. So, many different things the beam power velocity the beam diameter the thermal conductivity of the material the volume specific e, and finally, the melting temperature of the material. So, the idea behind this analysis is dimension analysis is to be able to step by step first predict all the independent parameters like in this case you have beam power beam diameter velocity of the beam etcetera in to the basic dimensions. So, basic detentions in this particular case, because we are using terms related to either work energy or velocity or temperature.

So, depth before basic dimensions mass length time, and temperature and. So, we express all these different independent parameters in terms of this basic dimensions. So, let us start with power power for example, is force in to distance per any time. So, the basic dimensions would be that a force that is M L T minus 2 times of L divided by T. So, this is M L square T minimum three similarly you have for velocity L T minus 1 d of course, is the diameter. So, it has the dimensions of length he here is thermal conductivity it would have the dimensions of M L lets just write this down here space and. So, k can be expressed in terms of M L T minus three theta minus one rows which is can be expressed in terms of M L minus L T minus 3 theta minus 1 row c which is can be expressed in terms of M L minus 1 t minus two theta minus 1 so on so forth. Of course, theta m is nothing but having the basic dimensions in temperature zee is l. So, according to the baking hams pi theorem the is followed to be able to see how many depend or independent parameters are there in this case the total number of parameters that are there are seven you can see this zee is one p is two v three d is four k five row c is six, and theta time is 7.

So, basically there are seven such parameters which are either dependent or independent, and they can be expressed in terms of only four basic dimensions that is mass length time, and temperature and. So, according to the baking hams pi theorem this n value happens to be 7 M the number of basic dimensions happened to be only four in this particular case meaning there by that there exists at least n minus m sub groups which are dimension less and. So, we have to somehow we able to correlate by raising this different quantities to different powers to arrive at this condition that at least three sub groups formulated by the various combination of this seven parameters would be having no dimensions or they would be completely dimensional, yes.

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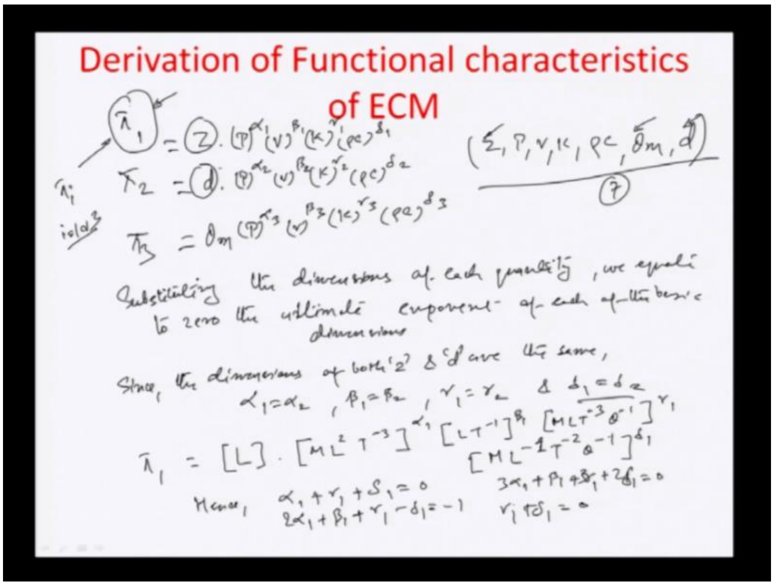


So, let us assume this three groups m m minus n equal to three groups to be equal to let say pi 1, and pi 2. And pi 3. So, we we can combine these or formulate these three independent subgroups pi 1 pi 2, and pi 3 by combining some one or all of these parameters together. So, these are completely dimension how many parameters we are already illustrated are these depth of melting temperature the beam power the velocity of rastaring o g beam the thermal connectivity volume specific heat how the material the temperature of melting, and the final beam diameter. So, there about seven such parameter which are dependent or independent, and the first estimate is shows that the only things which are independent of time here are the dimensions the length dimensions that is z and D, and temperature theta m the remaining all dimensions are dependent on time and. So, if you are to race the time dependent parameters to different powers we would arrived at a easier solution of this equation.

So, therefore, the idea is that lets actually formulate a subgroup pi one with length dimension zee to the power of one times of the other which are dependent or which are time based like power to the power of alpha 1 velocity to power beta 1 thermal conductivity to the power of gamma 1 times of volume specific key to the power of delta 1 similarly we have some other dimensional parameters like pi 2, which can be the represented in terms of diameter beams power to the power of alpha 2 velocity rastaring to the power of the beta 2 thermal conductivity to the power of gamma 2, and rows c volume specific heat to the power delta 2, similarly the other dimension which is temperature dimension is in terms theta m power to the power of alpha 3 v to the power of beta 3 k to the power of gamma 3 row c to the power of delta 3.

So, substituting the dimensions of each quantity we equate to 0 the ultimate exponent of each of the basic dimensions. So, we can call these set of pi 's pi i with i varying from 1 to 3, and since the dimensions of both z, and d are the same alpha 1 is equal to alpha 2 beta 2 equals to beta 2 gamma 1 becomes gamma 2 delta 1 becomes delta 2 as you can see here if supposing all the basic dimensions are equated to 0 this particular pi 1 would have a 0 dimension and. So, the remaining alpha 1 beta 1 gamma 1, and delta 1 is would all be sort of equal to length in verse for making these dimension less which means there by that, because this also has the same dimension al length l, and alpha 2 beta 2 gamma 2, and delta 2 would combine together to have again dimension they are in terms equal to each other they can equated to each other’s. So, that is why alpha 1 equal to alpha 2 and so on so forth. So, let us now pick up one of them, let us say pi 1, and try to represent this in terms of basic dimensions. So, this is dimension for z times of the dimension for power here which is M L square T minus 3 to the power of alpha 1 times of the dimensions for velocity L T minus 1 to the power of alpha 2 times of I am sorry beta beta 2 times of k which is actually again represented as M L T minus 3 theta minus 1 to the power of gamma 1 this is beta 1 times of M L minus 1 t minus 2 theta minus 1 times of dealt 1. So, alpha 1 plus gamma 1 plus delta 1 is equal to 0 twice alpha 1 plus beta 1 plus gamma 1 minus delta 1 equal to minus 1 thrice alpha 1 plus beta 1 plus gamma 1 thrice gamma 1 plus twice delta 1 equal to 0, and gamma 1 plus delta 1 is equal to 0, and solving all these equations.

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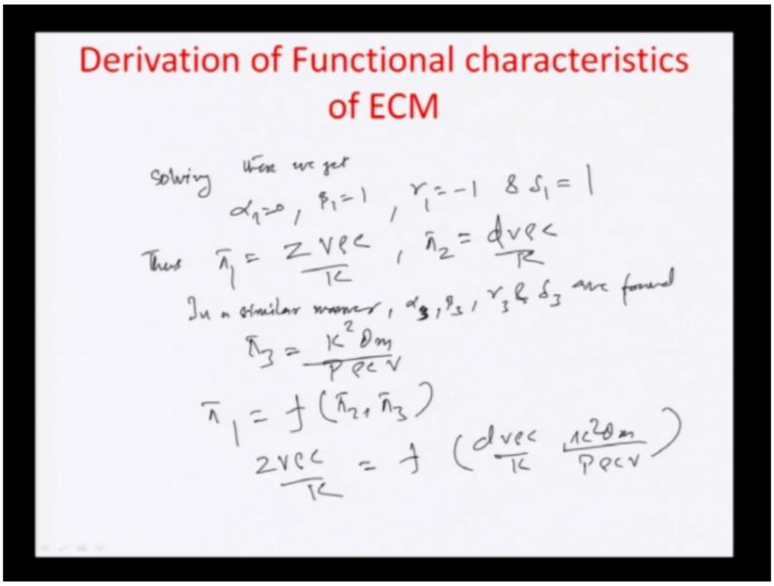


We get alpha 1 equal to 0 beta 1 is 1 gamma 1 is minus 1. And delta 1 equal to one thus pi 1 the first dimensional comes out a z we rows c by k pi 2 second dimension group plus group comes out to be v rows c by k in the similar manner alpha 3 beta 3 gamma 3 a b d delta 3 are found, and pi 3 that way emerges out to be k square theta m by power p times of rows c v. If we get a functional relationship pi 1 is f pi 2 pi 3 in this particular case pi 1 is z v rows c by k, and these can have a functional relationship with respect to the other two non dimensional numbers pi 2, and pi 3 d v rows c by k, and k square theta m by power p rows v.

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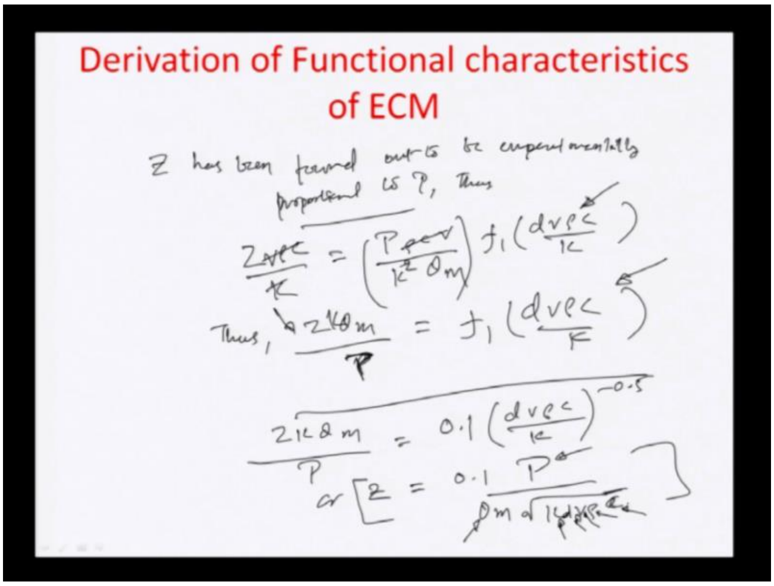


Psi has been found out to be experimentally proportional to p thus z. Rows C V by K comes out to be equal to power p times of rows C V by square of K theta m function f one d v c by k thus thus the only way to have the proportionality to power as linear the other term does not have a the power term in which it is inside the which is which is actually the function f one. So, it has been therefore. So, therefore, we arrive at term that if we just rearrange this a little bit this goes away this also goes away. So, you have zee theta m by k times of power p is equal to function of d v rows c by k.

Now if you do an experiment of the e b m where you observe the various relationships which happen between z theta m by z theta m k by power p on one hand, and this d v rows c by k another hand you do have such a experimental relationship merging from the from the absorbed data, and this can be written down this is more empirical by just doing surface this comes out to be z k theta m by p equal 0.1 times of D v row c by k to the power of minus 0.5 or in this case z becomes equal to 0 point one power p divided by theta m root of k v d row c.

So, that is how you can evocate z with respect to the the various dependent parameters the beam power the depth of melting temperature the k value thermal conductivity of the material the beam diameter velocity density specific heat so on so forth. So, in a nut shall we do have now a compression based on dimensional analysis experimental data of this e b machining, and we have already arrived that the relationship of how the temperature various with respect to the depth ah where the plot suggest that with the control or in the in the pulse duration on the variation in the pulse duration there is a gradual shifting of the depth of melting temperature towards the surface. So, having set these two things, I think we are pretty much ready for doing micro machining using e b m which will probably cover in the last few lectures where we will talk various aspects of resolution beam power so on so forth using this fundamental knowledge about the e b process.

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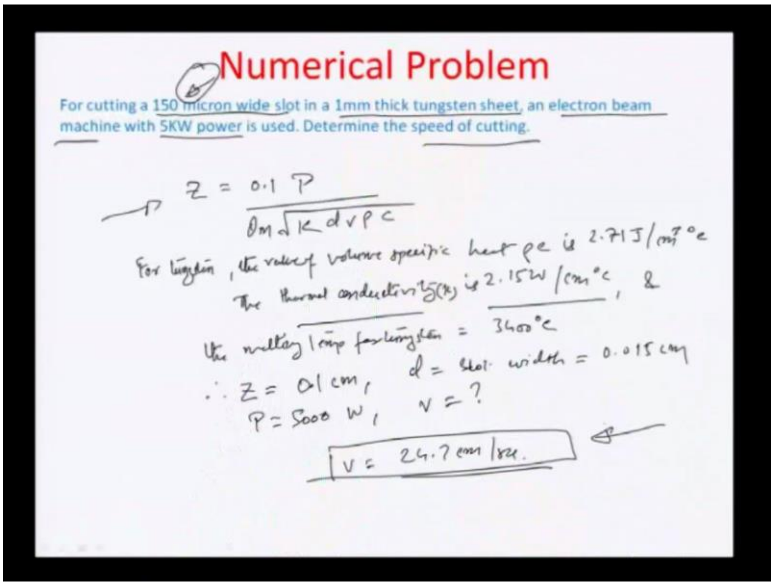


Lets now do some numerical example to strength, then over understanding in this particular area let us look at this a numerical problem that for we want cut a 150 micron white sort in a 1 mm thick sheet, and use an electron beam machining process with 5 kilo watt power, and we have to obtain the speed of cutting in this particular numerical example. So, we already know that there is a formulation which has been obtained with dimensional analysis, and experiments as zee equal to 0.1 times of power p divided by theta m root of K d v row c we already know for tungsten the value of volume specific heat row c is 2.71 joule per centimeters q degree celsius.

The thermal conductivity is 2.15 watts per centimeter degree Celsius, these are some material properties which can be obtained from any standard book, and the melting temperature for tungsten is around 3400 degree celsius therefore, the zee value can be expressed as 0.1 centimeter one millimeter diameter d of the beam can be equated to the slot width that you want to machine here, and this particular case the slot width is 150 micron, and the is in the best interest of the quickest machining step. So, it is 0.01 centimeters the beam power that is used is basically 5000 watts, and velocity has to be determined rastaring velocity can be easily determined from this relationship here in the velocity comes out to be equal twenty four point seven centimeter per second. So, in order to cut a small slot of 150 microns in a one mm tungsten sheet the amount of a speed that is used for cutting this slot is about 24.7 centimeter per seconds. So, cutting speed is not that fast. So, there is a lot of dwell time, and this helps in melting, and removal of the material like any other process would do and. So, that is how the e b m process works. So, if you may recall there was another way of estimating the the beam power which was done before it was mentioned that the beam velocity actually the rusting velocity of the beam actually obtained on a on a surface may be much much more in comparison to that predicted by that method.

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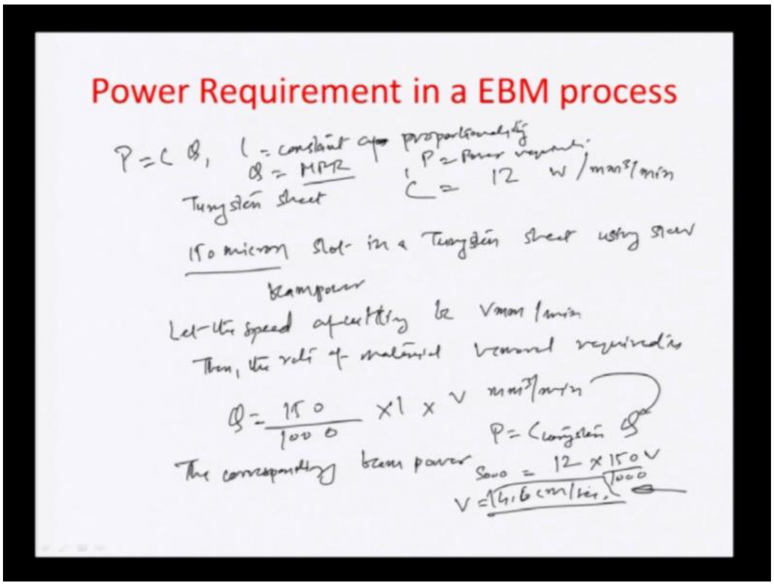


Lets us do a quick comparison to see how that is true. So, if made remember the power requisition in the earlier shields were given out by an expression P equal to C Q, where c was the constant of proportionality. And the value for example, for in this particular case, it is a tungsten sheet the c value experimentally absorbed in case tungsten sheet come out be about 12 watts per millimeter cube per minute q. Of course, is the M R R material removal rate P is the total amount of power which is needed. Now we also talked about the similar kind of set up where we were cutting a hundred and fifteen hundred and fifty micro slot in a tungsten sheet using five kilo watt beam power. So, let the speed of cutting be v m m per minute, then the rate of material removal required is Q equals 150 by 1000 of 1 times of V m m q per minute the corresponding beam power is given by P equals C tungsten times of the material, Removal rate q being estimated above here, and if we assume this power to be 5000 watts as is the case given in the question, and c tungsten to be about close to 12 times of these 150 by 1000 v we obtain a velocity v of 4.6 centimeter per second. So, this is much much small as you can seen comparison to what we have obtained using dementia analysis, and a other. So, in criteria general the actual velocity of rastaring is much much more in comparison to the velocity is predicted by a simplistic equation P is equal to C Q.

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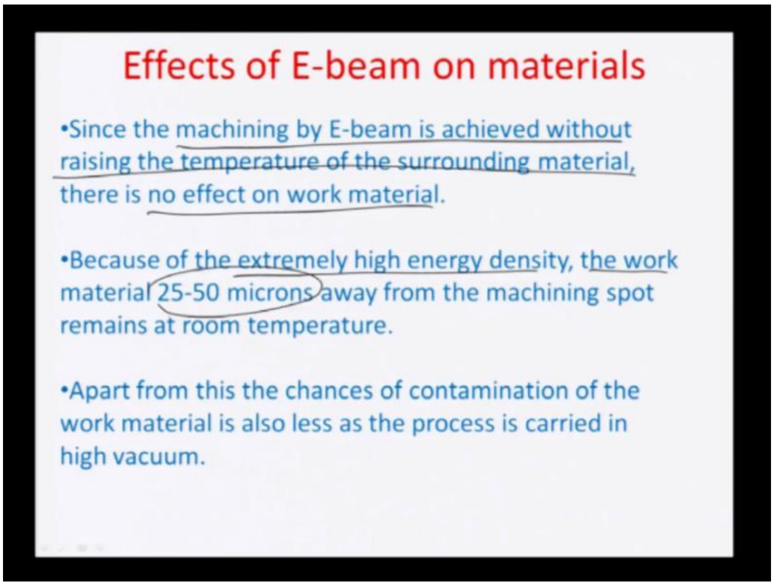


The other important point about vb in before we stop this lecture is that which machine by e beam is achieved without raising the temperature of the surrounding material. There is no effects which on the work material. So, it is the very high resolution process as been illustrated before the surrounding material really remains an effected, because of the extremely high energy density the the work material even up to the extent of only 25 to 50 microns away from the machining spot that still remains at room temperature. So, whatever deliverance of heat energy is associated with the e d m process is really limited to the work area a for, which it is intend or targeted. So, an distances are small as about fifty microns on that work area by an a large an effective. So, e beam is very good process as for as machining accuracy is concerned, and also one more factor is that the chance of the contamination are very less, because the process is mostly in high back you, and therefore, a material getting formulated in to wet substituted state you know are some other state by combination with a reactance which are present of the periodical which are present that most of here that in this case gets limited by the fact that the beam is within column which has high vacuum. So, we this would like to, and this t he lecture on e beam machine in the next lecture I would talk about little more details of laser machining in process an how that is suitable for doing micro machine machining in micro manufacturing an following which all this process how they can be used in actual membs technology, and would be illustrated in r ate details.

Thank you.