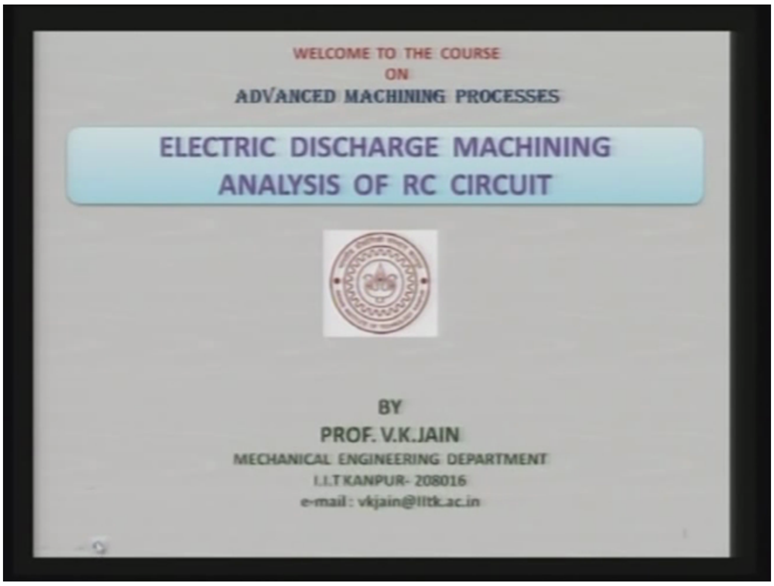
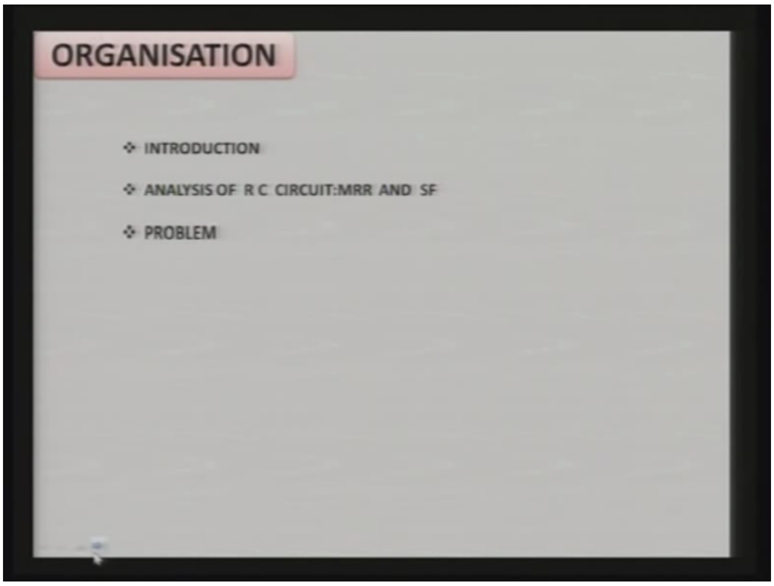
Advanced Machining Processes
Prof. Vijay. K. Jain
Department of Mechanical Engineering
Indian Institute of Technology Kanpur
Lecture No 18

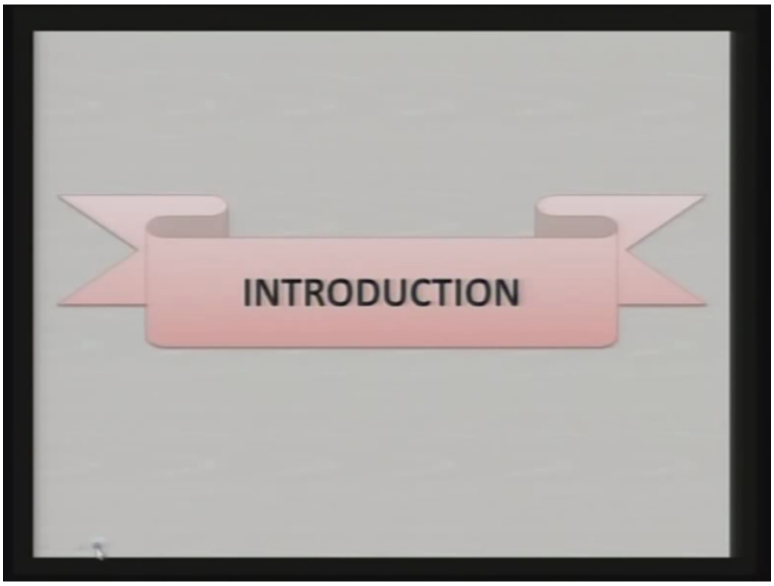
(Refer Slide Time: 0:21)

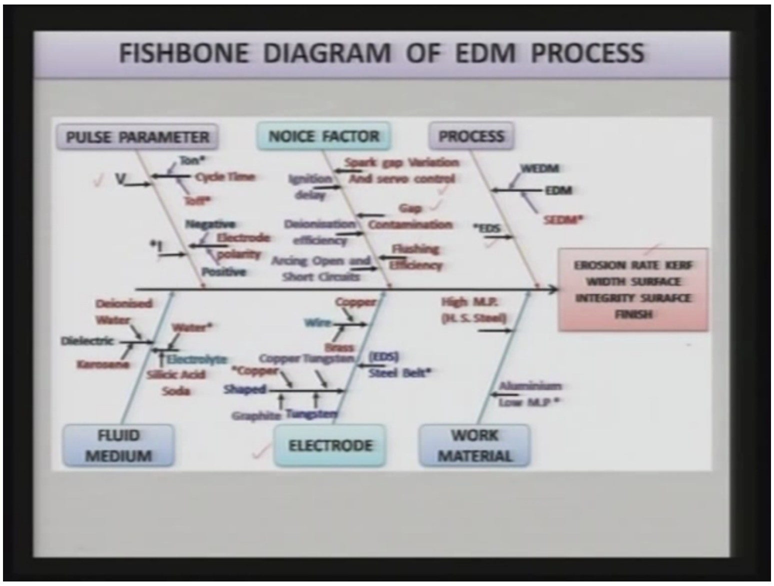




Welcome to the course on advanced machining processes. Today we are going to discuss electric discharge machining analysis of RC circuit. The organization of the talk is like introduction, analysis of RC circuit reference to material removal rate, maximum power delivery to the discharging circuit and surface finish. Then I will deal with some problems related to electric discharge machining process.

(Refer Slide Time: 1:04)





Now from the discussion of the last 2 lectures here are the various parameters which affect the performance of the electric discharge machining process. Let us just see what are those parameters which we have already discussed in the last 2 lectures? First one is the voltage supplied across the circuit in general and breakdown voltage of the circuit. Then current that is flowing in the circuit that is the charging circuit is there discharging circuit is there that we will discuss today.

Then we are using the pulse power supply in EDM, so the on-time of the power supply as well as the off time both are important and the on-time plus of time makes what is known as cycle time. Electrodes can have either normal polarity that is where tool is negative workpieces is positive or reverse polarity where tool becomes positive and workpiece become negative. These are the pulse parameters which affects the process performance we have already seen. Then comes the fluid medium, we can use the deionised water as the dielectric but there are various kind of the oils that are used as the dielectric mainly kerosene is one of them was commonly used. Then there is the electrodes you can use the copper as the electrode material and when you are using wire EDM as we are going to discuss shortly then there you can use copper wire as the electrodes.

Also you can use copper tungsten as the material for the electrode that is the tool, copper, graphite or tungsten they are also used as the material for making the tool or the electrodes and you have to make them in different shapes depending upon what final shape you want on the workpiece. Work material is decided by the designer and it does not really matter whether it has a low melting point or high melting point, you can use whatever is specified by the designer. Then there are other parameters like ignition delay which I mentioned to you, once the breakdown voltage is reached then for how long the ignition delay is there, it may be 1 microsecond, 2 microsecond or so that also affects the performance of the process and 2nd very important point is the deionisation efficiency.

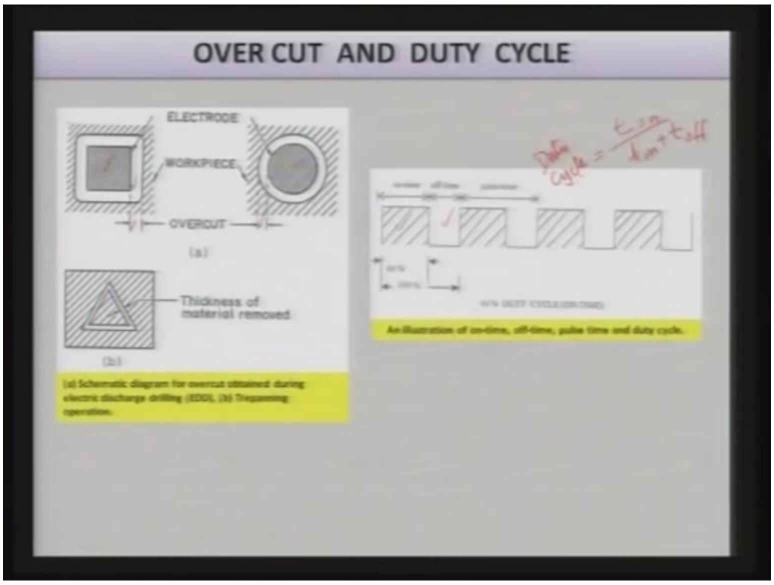
Once the off time of the cycle is there how long it takes to deionise the dielectric, so that the next pulse starts affecting or charging the dielectric. Then there is the arcing open and short circuits which we have not discussed. Then spark gap variation is another very important point that the gap between the tool and the workpiece, it may be in the front gap it may be in the side gap and how the servo motor or servo system is going to control this particular gap during the process is also an important point. It will decide what is going to be the total cycle time required for machining or shaping and sizing a component this is very much dependent on the servo control also.

Another important point that we have discussed is the gap contamination, once the EDM process starts then you have the reaction products or the debris is in the interelectrode gap, you have the gases evolved during the EDM process due to the highly intensified heat generated in the localised area, so the dielectric also vaporises and you have all these gases were the ones the breakdown voltage is reached then you have the plasma column and the flushing efficiency is another very important point which decides the performance of the EDM process. If the process is not highly efficient in flushing out, the debris, the reaction products and the used dielectric and definitely the total cycle time is going to be much larger than the expected one.

You can have a wire EDM process that we will discuss after this chapter and then EDM we have discussed there and then there is a process called EDS electric discharge sawing process where you can cut the material into 2 pieces or more than 2 pieces using the spark. Now what are…how are you going to evaluate the performance of the EDM process or wire EDM process. Then there is the erosion rate or material removal rate, characteristics of the (()) (7:08) in case of wire EDM process integrity of the finished surface this is very important point because EDM and wire EDM are the thermal processes that is their heat dependent processes where material is melted and vaporised due to the heat generated at the point of sparking. So since the temperature is very high in the localised area, it normally heats to what is known as micro cracks and micro cracks in the machine component are detrimental to the performance of that particular opponent.

Apart from that due to the high temperature gradient in the localised area and surrounding area, the thermal residual stresses are created in the machine component that is another point which one should take into consideration while evaluating the performance of the EDM process. So this diagram shows us what are the various important parameters in EDM and wire EDM process and there are also the parameters with the help of which you can evaluate you performance of the EDM process.

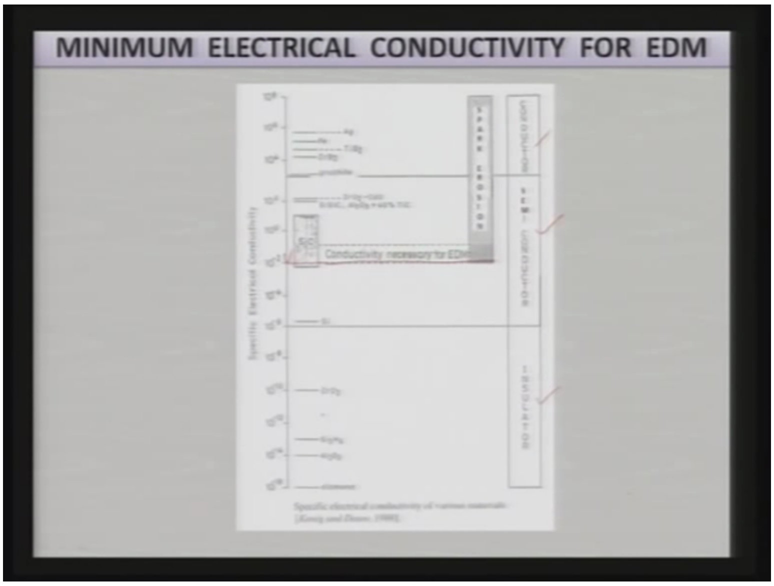
(Refer Slide Time: 8:35)



We have also discussed in the earlier 2 lectures the over cut obtained during EDM process in general and drilling process in particular, so it is very clearly shown over here at here if you see the diagram on the left side this is the tool and this is the cavity which has been machine with the help of this and over cut is clearly shown over here. This tells that is the radial over cut that is the gap or the distance in the dimensions on one side of the electrodes and the machine cavity and if you take whole of it then it becomes double if it has the same over cut on both sides or the same thing you can see here when there is a cylindrical or circular hole being drilled then you can clearly see the over cut shown over here or there can be a trepanning kind of the operation again you can see the over cut represented by thickness of the material removed.

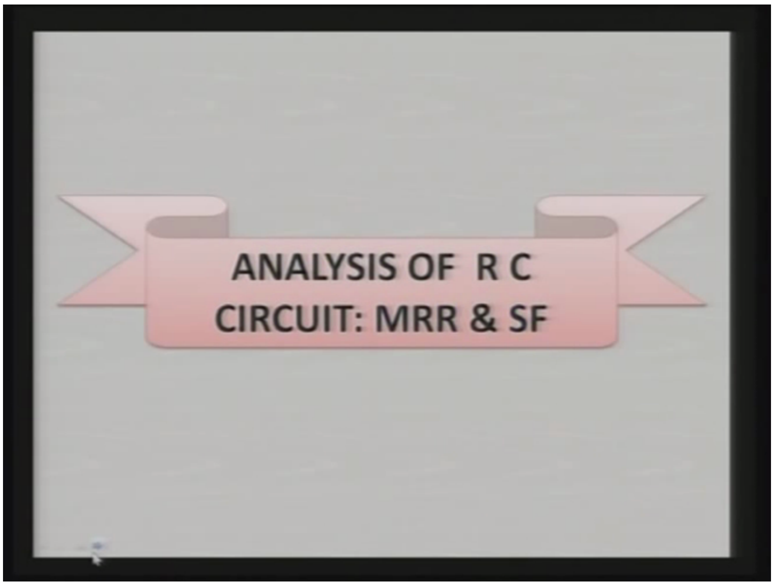
Now I have mentioned to you just now and in the earlier classes also that the is the on-time and off time of the pulse that may be the voltage pulse, now in case of voltage pulse this represents the on-time that is when the voltage is on and when there is no power supply it becomes the off time and you can see clearly that there is a certain width of on-time and certain width of off time. The ratio of on-time divided by on-time plus off time that is given like this on over t on plus t of. This tells you that duty cycle and this is very important, it decides the material removal rate also and in place of square voltage pulses as shown over here they can be of other shapes also which are used for minimising the tool wear and accordingly you can decide what is going to be the on-time and what is going to be the off time.

(Refer Slide Time: 10:59)



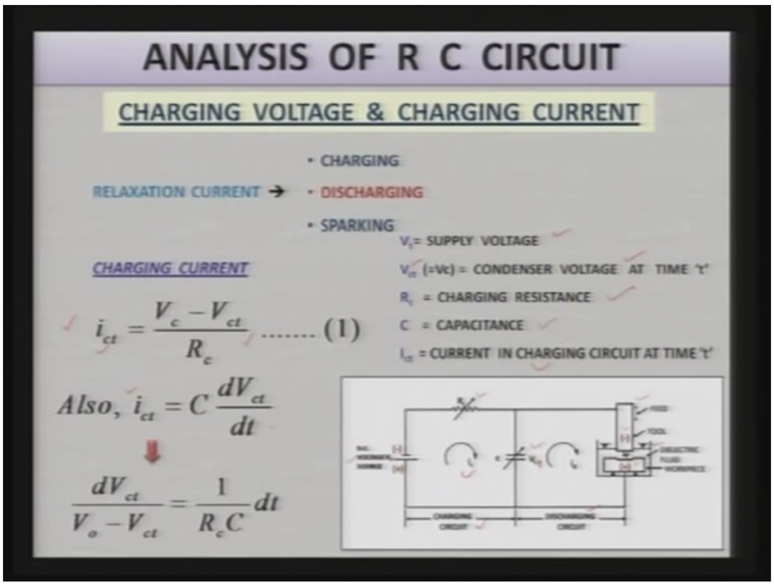
I have also mentioned to you that for machining any material by EDM process you need to be electrically conductive. There is a certain minimum electrical conductivity the workpiece material should have otherwise it cannot be machined by the EDM process, so you can see here the all the materials are divided into 3 categories, one is the conductor another is the semiconductor 3rd is the insulator, now in semiconductor also to a certain point as shown over here this is the minimum necessary conductivity which any material should have to be machined or processed by EDM process and you can clearly see here is a certain value which is represented in here in terms of specific electrical conductivity and many people have been designing the material so that they can be easily machined by the EDM process means they will have this certain minimum conductivity because without this minimum conductivity they cannot be shaped and size by EDM process and to some extent by the ECM process also.

(Refer Slide Time: 12:16)



Let us see the analysis of RC circuit and how to calculate material removal rate? How to calculate maximum power delivery to the discharging circuit and surface finish especially in case of RC circuit?

(Refer Slide Time: 12:40)

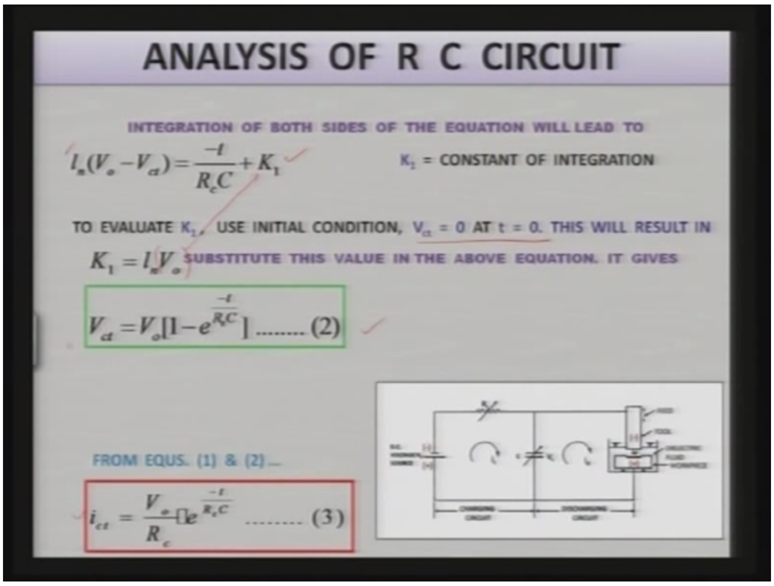


Now there is in relaxation…this is also known as relaxation circuit and you have the charging, discharging and sparking 3 phases are there which I will show you in the diagram. So you can see here V s is the supply voltage which you are supplying across the terminals, V ct condense voltage at time t, R c is the charging resistance, C is the capacitance and I ct is the current in the charging circuit at time t and this is well-known equation you can utilise it to calculate the current in the charging circuit i ct that is given by V c minus V ct over R c and this is the equation one.

You can clearly see in this particular diagram that there is a supply voltage here DC supply voltage V 0 or V s here it is written as V s and here is the RC that is the charging resistance and here is the condense C where you can calculate the voltage across the condenser at any time t and it is represented by V ct here it is just resistance V c so you can make if V ct also and the current flowing in this discharging circuit is given by ID and in charging circuit is given by IC and on the other right side you see tool is there which is connected to the negative terminal of the power supply and workpiece is there connected to the positive terminal of the power supply and the dielectric fluid is there and the workpiece is shown plus and tool is shown as negative.

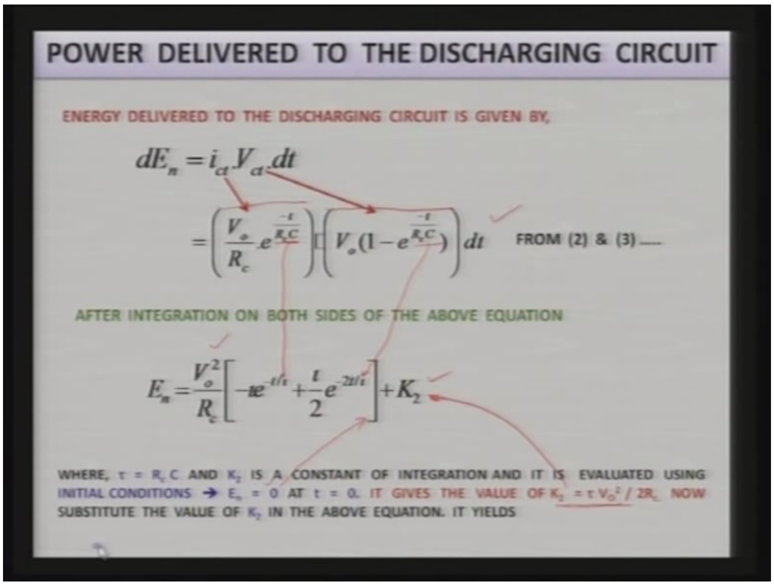
Now here is the charging circuit, this is the discharging circuit and with the help of this particular equation you can calculate the current IC in the charging circuit also i ct that is the current in the charging circuit is given by C dV ct over dt and since this and this they are equal so you can equate this right-hand side of both the equations, so you get dV ct over V 0 minus V ct is equal to 1 over R c C into dt.

(Refer Slide Time: 15:12)



And using this particular equation integrate integration of both sides of this equation will lead to l n that is an natural logarithm of V 0 minus V ct equal to minus t over R c C plus K 1, where K 1 is the constant of integration, we integrated the earlier equation given in the earlier slide. Now to evaluate K 1 that is the constant of integration use the initial condition V ct will be 0 at time t is equal to 0 and this will result if you substitute this value in this particular equation then you will get that K 1 is equal to natural log l n V 0 that V 0 is like this. Then what you can do you can substitute this value of K 1 over here in the earlier equation then it will give you V ct is equal to V 0 that is the supply voltage 1 minus e raise to power minus t over R c C and this help of this particular equation you can find out the voltage in the charging circuit. From this equation one in the earlier slide and this particular equation 2, if you use both these equation then you can also calculate the current i ct it is given by V 0 over R c e raise to power minus t over R c C. So we can calculate the V ct and we can calculate the i ct both.

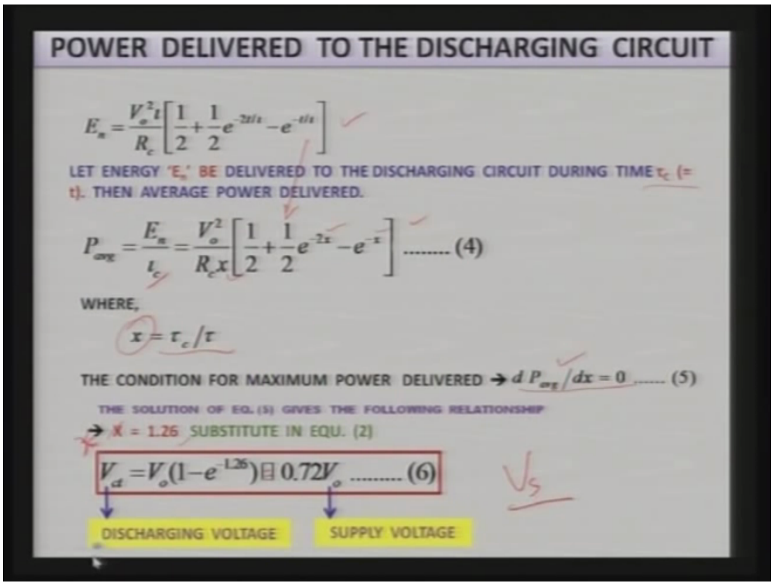
(Refer Slide Time: 17:15)



Now the question arises power delivered to the discharging circuit, how to calculate that? Energy delivered to the discharging circuit is given by, dE n that is equal to i ct that is the current V ct is the voltage and dt is the time of which this current is supplied. If we substitute the value of i ct from the previous slide and V ct from the previous slide then you will get V 0 over R c e raise to power minus t over R c C multiplied by V 01 minus e raise to power minus t R c C into dt that you can obtain equation 2 and 3. So this is the value of the i ct, this is the value of V ct.

Now integration on both sides of the particular equation will result as E n that is the energy is equal to V 0 square R c minus te raise to power minus t over tau plus 1 tau over 2 e raise to power minus 2 t over tau plus K 2 where again K 2 is the constant of integration where tau is the R c C, this tau R c C has been replaced by this tau or this R c C has been replaced by this tau and K 2 is a constant of integration and it is evaluated using again an initial conditions that is energy supplied at time is equal to 0 will be 0, it gives the value of K 2 is equal to tau V 0 square by R c C. This initial condition is substitute in this particular equation then you will get K 2 is equal to tau V 0 square divided by 2 Rc and this value of K 2 can be placed over here then substitute the value of K 2 in the above equation.

(Refer Slide Time: 19:31)

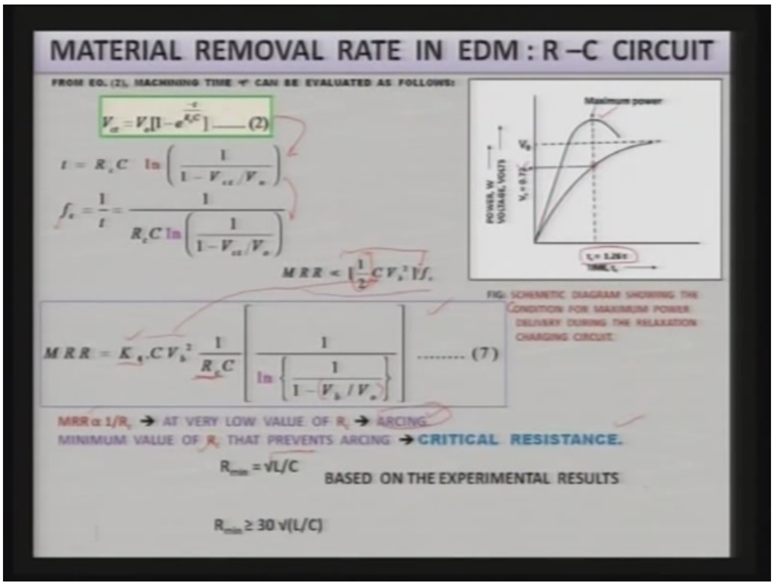


It will result E n is equal to V 0 square tau over R c multiplied by 1 by 2 plus 1 by 2 e raise to power minus 2t tau t over tau minus e to power minus t over tau. This with the help of this particular equation you can calculate what is the energy supplied. Now let energy E n be delivered to the discharging circuit, this is discharging circuit is the one where tool and workpiece are connected they are in the machining zone. Now during the time let tau c is equal to t then average power delivered will be given like this that is P average is equal to we are dividing it by tau c E n over tau c that is the time that will give you the power V 0 square over R c x 1 by 2 this you can obtain here by substituting the value of this 1 by 2 e raise to power minus 2 x minus e raise to power minus x, where x is equal to tau c over tau, this is important substitution.

Now when we have this…now we can find out the condition for maximum power delivered to the discharging circuit because we are always interested that the power delivered to the discharging circuit should be maximum so that the spark is having higher energy or and you will get higher material removal rate. So the condition that we know that for having the maximum power delivery to the discharging circuit this particular condition should be satisfied that is d P average over dx is equals to 0 because x is the function or variable over here is given over like this and this you can find out here x is there and here also.

So the solution of equation 5 when we solve this particular equation it will give the following relationship that is x is equal to 1.26, if we solve this equation we will get this and this is small x not capital x, x is equal to 1.26, now we can substitute this value of x, substitute it in equation 2 earlier then we get V ct is equal to V 0 1 minus e raise to power minus 1.26 and this is equal to 0.72 V 0 that means discharging voltage should be equal to 72 percent of the supply voltage to get maximum power delivered to the discharging circuit, this is very important relationship which have going to use while solving the problems. So this is the supply voltage V 0 which is also represented sometimes as V s.

(Refer Slide Time: 22:56)



Now we are always interested what is going to be the material removal rate either gram per second or gram per minute or volumetric material removal rate in terms of cubic millimetre per minute or per second. So from earlier equation 2 machining time t can be evaluated as follows, now this is the relationship your already know V ct is equal to V 0 multiplied by 1 minus e raise to power minus t over R c C. Now from this equation we can arrive at t equal to R c C l n natural log of one over 1 minus V ct over V 0.

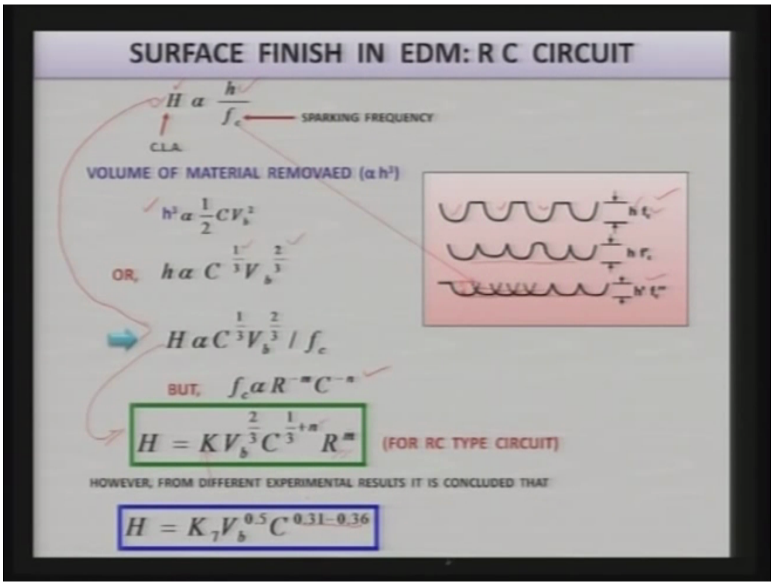
Now but if we know the time or cycle time then from that cycle time can also calculate the frequency of sparking that is nothing but frequency of sparking is equal to 1 by over t and if we substitute the values from here in 1 over t we will get this particular equation where l n is the natural log. Now we already know that volumetric material removal rate or material removal rate is directly proportional to the energy of each spark that is given by half C V b raise to power 2 that is half C V b square and multiplied by number of the spark taking place per second, so that will give you the material removal rate, so if you simplify this you will get MRR is equal to K 4 that is the constant of proportionality CV b square that is what you get from here and 1 by R c C 1 over l n 1 over 1 minus V b over V 0 that is what you get.

Now here this 1 by 2 has been included in the constant of proportionality K4 there is to be taken care of otherwise if you are using it separately then the value of K4 will be different. Now here if you see the diagram, schematic diagram showing the condition for maximum power delivery during the relaxation charging circuit. Now you can see as we saw in the earlier relationship, the maximum power delivery is going to be at x is equal to 1.26 that is over here and that is occurring at 0.72 as the supply voltage, 0.72 of the supply voltage, so you can see here that relationship is shown over here and this is the maximum power delivery. So MRR now so this particular equation is very important for calculation of the material removal rate provided you know the value of supply voltage C that is the capacitance, R c charging assistance and constant K4.

Now it is very clear from this that MRR material removal rate is torsional to 1 by RC that is given over here inversely proportional to RC that is charging assistance and this simply means that if you keep on decreasing the value of RC material removal rate will keep increasing, so at very low value of RC you can keep the decreasing eat but there is a limit, if you decrease the value of RC beyond that particular limit and what will happen? Instead of sparking you will get what is known as arc or arcing will take place and we are not interested in arcing in EDM process because it is harmful for both.

It will damage the tool as well as it will damage the workpiece, so we are interested all the time in sparking in EDM process rather than arcing, so there is a minimum value of RC that prevents the arcing and that value of RC or the charging assistance is known as critical resistance and that critical resistance of that minimum resistance at prevents the arcing is given by under the root L by C where L is the inductance and C is the capacitance. It is based on the experimental results people conductor lots of experiments and then they found that in fact R minimum is equal to 30 multiplied by under the root L by C, this is valid for a certain machining conditions and certain tool and workpiece material.

(Refer Slide Time: 28:08)



Now suppose you are given the details of the RC circuit as we have seen in the earlier slides, can we evaluate the surface roughness that you are going to get with the help of that particular EDM process and the RC pulse generator? Now before that let us see here this is the kind of the crater you are going to create if you are giving a if you are given certain machining conditions, now you can clearly see this is the crater and here no spark has taken place, so you get un-machined area, h is the depth of the crater and f c is the frequency of charging. Now you will get that the frequency of charging changes you can get this particular type of the crater formation and they will be close to each other.

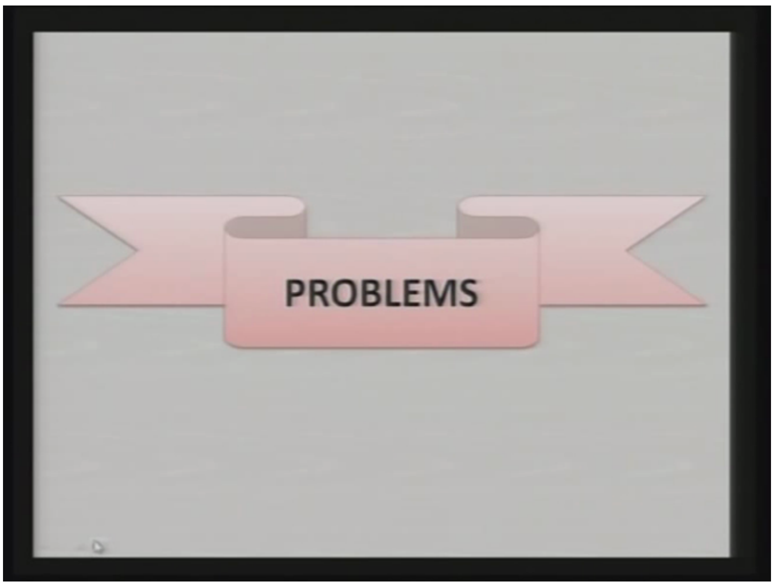
Quite possible at different frequency or due to the moment of the workpiece in x and y direction you will get the overlapping craters and in this overlapping craters you can clearly see that initial is this depth but when overlapping is there than this depth reduces substantially and you have already seen that if you increase the frequency of charging the surface finish improves this is one of the reason how the surface finish is improving with larger frequency because the craters get overlapped with each other and their Ra value or of central line average value is decreasing as shown in this particular 3rd one and here actually the depth of the crater is reducing and that is another reason why you are getting a better surface finish, so H capital H that is the center line average value is proportional to h that is the depth of the crater and f c is the charging frequency because larger the charging frequency lowers the value of h and larger the value of small h that is the depth of crater larger will be the CLA value.

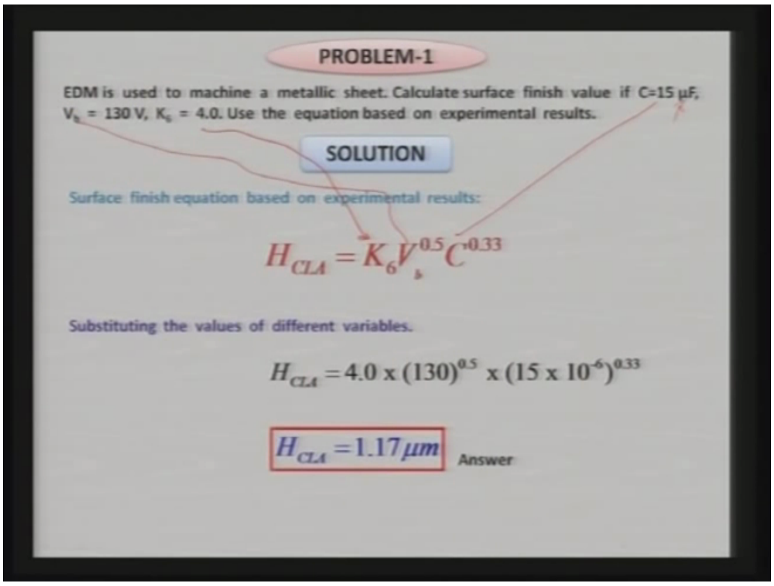
Keeping this in mind volume of material remover will be proportional to h cube whatever is the height of the crater if you assume this crater as the hemisphere in the shape then the volume of the material removed will be proportional directly proportional to the h cube. So h cube and this value of h or h cube will depend upon the energy per spark, what is the energy? More the energy deeper will be the crater larger will be the value of h, less the energy shallower will be the crater and smaller will be the value of h.

So that we can write h cube is directly proportional to half CV b square or you can write down h that is the depth of the crater proportional to C multiply C raise to power 1 by 3 and V b raise to power 2 by 3. So you can write down actually because from this particular equation now you can write down this equation H is proportional to C raise to power 1 by 3 V b raise to power 2 by 3 divided by f c that is the sparking frequency but we know that f c that is the frequency of sparking is proportional to some R raise to power minus m and C raise to power minus n where m and n are the constants.

Using this particular relationship this equation can be written H is equal to K V b raise to power 2 by 3 C raise to power 1 by 3 plus n and R raise to power m, now here again K is the concept of proportionality you have to evaluate it with the help of the experimental results. However, from different experimental results it is concluded that H is equal to some constant K 7 or K it does not matter V b raise to power 0.5 C raise to power 0.31 to 0.36 that is the value of the constant n plus 1 by 3 vary in this particular range and whatever is this that is taken care of by the constant.

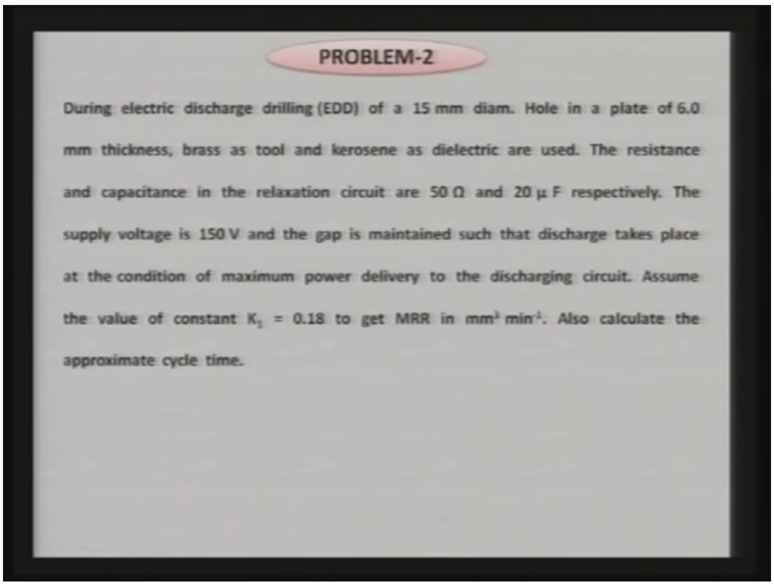
(Refer Slide Time: 33:04)





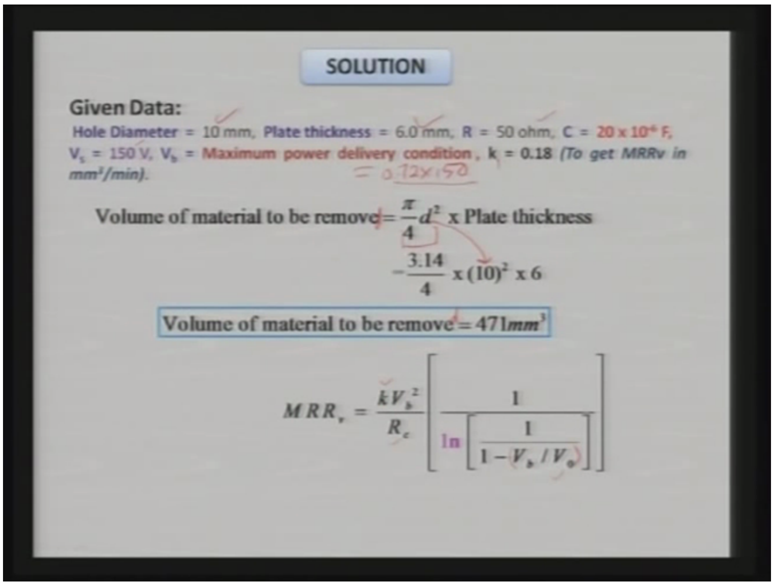
Now using this particular form we will…I will try to solve some of the problems related to EDM process, problem 1 is very simple let us see what it says, EDM is used to machine a metallic sheet. Calculate surface finish value if C that is the capacitance is 15 microfarad, big voltage 130 volt, K 6 constant is 4. Use the equation based on experimental results. Surface finish equation based on experimental results is as follows H CLA is equal to K 6 V b raise to power 0.5 and C raise to power 0.33 we are already given the value of c over here and V b is given over here, so you can use these and K 6 is also given over here. Substitute these values this particular equation then you will get H CLA is equal to 4 into 130 raise to power 0.5 and 15 into 10 raise to power minus 6 because this is an microfarad 10 raise to power minus 6 and 0.33. If you solve this you will get H CLA is equal to 1.17 micron.

(Refer Slide Time: 34:39)



Now let us take the 2nd problem, during electrode discharge drilling of a 15 millimetre diameter hole in a plate of 6 millimetre thickness, brass as tool and kerosene as dielectric are used. The resistance and capacitance in the relaxation circuit are 50 ohm and 20 microfarad respectively. The supply voltage is 150 volts and the gap is maintained such that discharge takes place at the condition of maximum power delivery to the discharging circuit. Assume the value of constant K 1 equal to 0.18 to get MRR in cubic millimetre per minute. Also calculated the upper estimate cycle time.

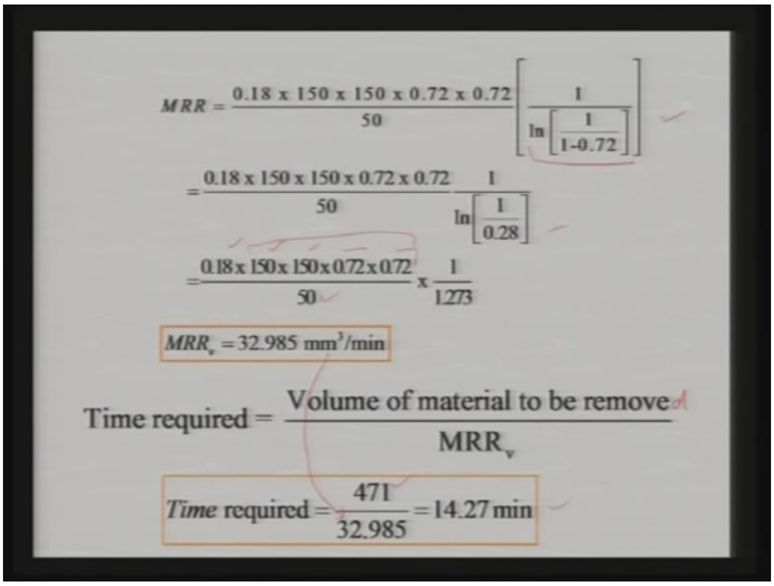
(Refer Slide Time: 35:33)



We are given with the following data hole diameter to be drilled is 10 millimetre, plate thickness is 6 millimetre, resistance 50 ohm, capacitance 20 into 10 raise to power minus 6 farad because was given in microfarad, supply voltage 150 volts, breakdown voltage of the dielectric maximum power delivery condition that is 0.72 into supply voltage this will come out to be 0.72 into supply voltage is 150, so you can calculate what is the maximum power delivery condition and k is 0.18 or k1 as written in the earlier slide to get MRRv in terms of cubic millimetre per minute.

So what is the volume of material to be removed in drilling this particular hole? That is equal to pi by 4 d square this gives you the cross-sectional area of the hole to be drilled and the plate thickness. Substitute the value of d that is the 10 millimetre as the diameter of the hole as given over here and thickness of the plate is given as 6 millimetre over here, so substitute these values and calculated you will get 471 millimetre cube as the volume of the material to be removed during drilling operation. So now let us see what is the equation for calculation of the volumetric material removal rate in EDM using the RC circuit that is given by k V b raise to power 2 R c multiplied by 1 over natural log 1 over V b minus V 0? Now let us substitute the values because we are given which the value of k as 0.18. V b as given over here 0.72 into 150, RC charging resistance is given as 50 ohm and supply voltage is already given as 150 volt either V s or V 0 both are the same thing.

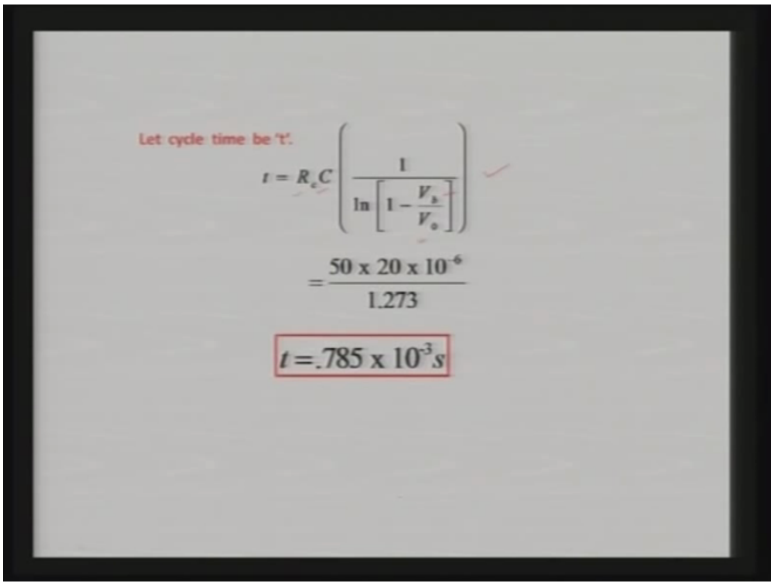
(Refer Slide Time: 38:01)



Let us substitute this value in the equation like this over here and you can find out this natural log of this particular factor you will get 0.28 over here and if you simplify this you get like this. Here this is K 1 supply voltage square over there and 0.72 0.72 is multiplying factor so that you really get V b square from this particular factor this is the resistance and this is that particular factor, so you get volumetric material removal rate as 32.985 cubic millimetre per minute.

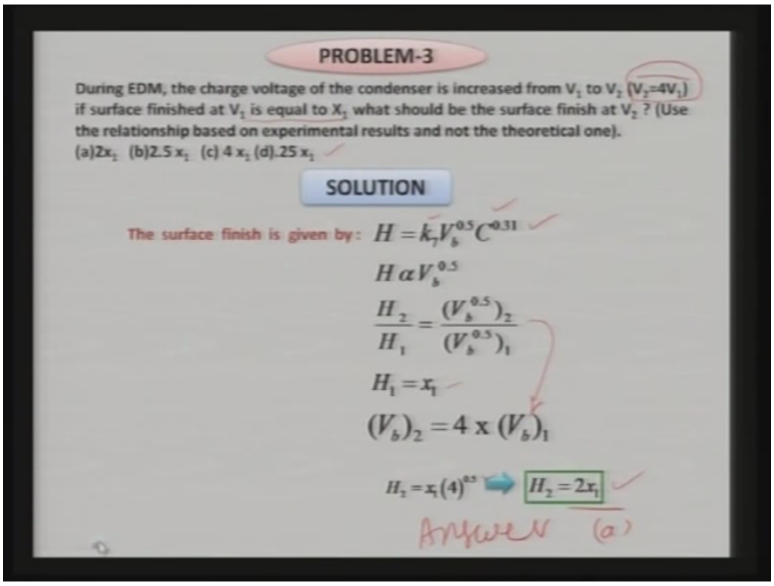
Now we want to calculate what is the time required for drilling the hole, so for that purpose first we should know what is the total volume of the material to be removed while drilling the holes and what is the volumetric material removal rate of the process. If you divide first by the second one then you will get the time in terms of minute, so you will get time required as 14.27 minute because 471 is the one which was calculated earlier as the volume of material to be removed and 32.985 is this what we have calculated as volumetric material removal rate, so you get 14.27 minute as the time required for drilling the hole.

(Refer Slide Time: 39:30)



Now we are also interested in knowing what is the cycle time t, so we already know the equation for calculation of the cycle time t is equal to R c C 1 over ln 1 minus V b over V 0, we already know the value of R c C, V 0 and V b. Substitute the value to get this particular value, this comes out to be 0.785 into 10 raise to power minus 3 second that is this the time required for one cycle.

(Refer Slide Time: 40:08)

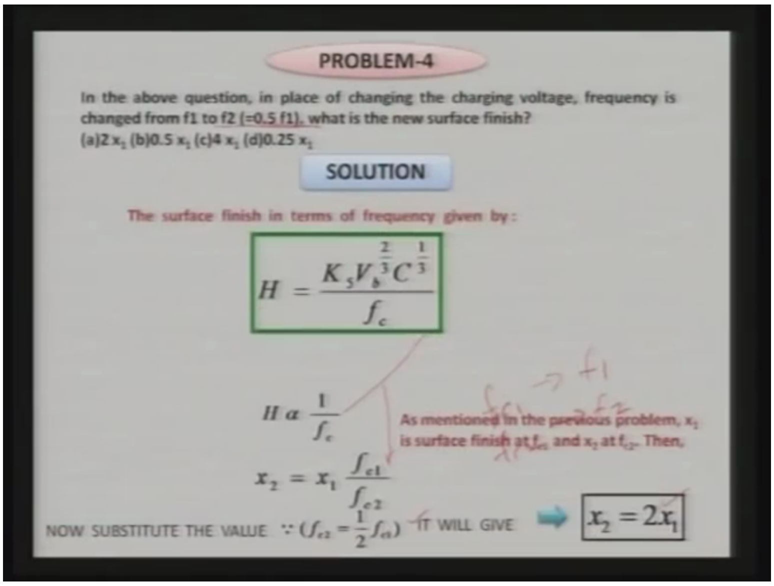


Let us take the next problem that is the problem 3, during EDM the charge voltage of the condenser is increased is equal to X 1 micro-meter, what should be the surface finish at V 2 and V 2 is already given here is equal to 4V 1. Use the relationship based on experimental results and not the theoretical one. Now these are the 4 options given to you to get the correct answer. One of these will be the correct answer. Let us find out how to solve or how to give the correct answer? The surface finish is given by the formula H k 7 V b raise to power 0.5 C raise to power 0.31.

Now H we know is from this particular equation we can easily see that H is proportional to V b raise to power 0.5 because this factor C and K 7 will remain the same in this particular case then we can write that H 2 that is the CLA value in the 2nd case or that is with supply voltage V 2 and H 1 with the supply voltage V 1 which becomes V b raise to V b 2 raise to power 0.5 divided by V b 1 raise to power 0.5 and we know H 1 that is the surface finish in the 1st case is x 1 that is already given over here in the problem, so we get V b 2 is equal to 4 from this particular if we substitute the value you get V b 2 is equal to 4 multiplied by V b 1. Substitute the value then you get H 2 is equal to x 1 multiplied by 4 power 0.5 and this will give you H 2 is equal to 2x 1.

That means in 2nd case the surface finish is going to be 2 times x 1, this is the RA value and that means if RA value is increasing that simply means the surface finish is deteriorating and this is quite obvious because as the voltage is increasing from V 1 to V 2 surface finish is going to be poorer and that is what you get that H 2 in second case the CLA value becomes 2 times the CLA value in the 1st case that is the V 1 voltage. So it is simple one, so this becomes…so you have to write the answer as a is correct.

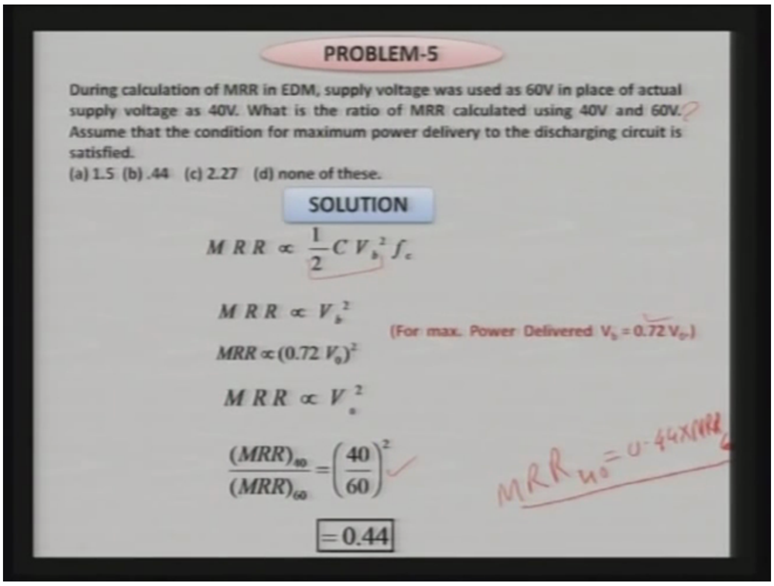
(Refer Slide Time: 43:04)



Now in the above question that is the problem 3, in place of changing the charging voltage that was V 1 was changed to V 2, frequency change from f1 to f2, frequency is frequency of sparking is changed to f2 and f2 is equal to 0.5 f1 is half of the frequency of f1. What is the new surface finish or what is the new value of surface roughness that is RA value? 4 options are given again 2x 1, 0.5x 1, 4x 1 and 0.25x 1. Let us see what is the correct answer? The surface finish in terms of frequency is given by H is equal to K 5 V b raise to power 2 by 3 C raise to power 1 by 3 f c. This is the theoretical equation and H proportion to 1 by f c, so we get x 2 equals to x 1 f c1 over f c2 from these 2 equations you can drive this one.

Now we are given with f c1 we are given with f c2, f c2 is given in terms of f c1, f c1 here is nothing but f 1 and f c2 here is nothing but f 2 given the problem. So as mentioned in the previous problem x 1 is surface finish at f 1 and x 2 is surface finish with f c2 then you get to substitute the value, then you get f c2 is half the value of f c1, this is given over here. Now if you substitute this particular value then you will get x 2 is equal to 2x 1 that means when frequency of sparking is decreasing then surface roughness is becoming poorer that means it becomes double or what you get in case of f1 that means RA value increases in second case and that means deterioration of the surface finish and it is quite obvious as I have mentioned in the earlier lecture that as frequency increases surface finish becomes better, here frequency is decreasing, so surface finish becomes poorer.

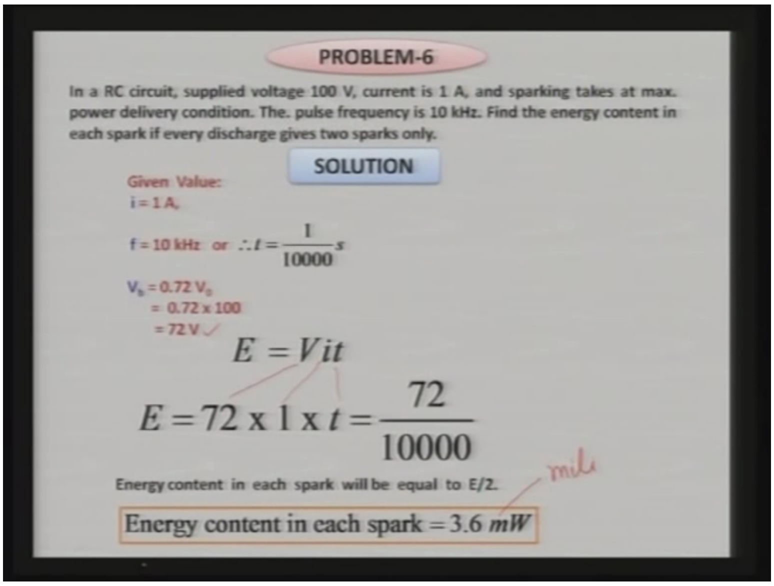
(Refer Slide Time: 45:35)



Next problem says that during calculation of MRR in electric discharge machining process are supply voltage was used as 60 volt in place of actual supply voltage as 40 volt. What is the ratio of MRR calculated using 40 volt and 60 volt? That is the question over here, assume that the condition for maximum power delivery to the discharge circuit is satisfied. 4 options are given 1.5 the ratio of this MRR, 0.44, 2.27 and none of these. MRR we know is proportional to 1 by 2 CV b square into f c, CV b 1 by 2 CV b square is the energy supply and f c is the frequency. So we can see MRR is directly proportional to the V b square that is the breakdown voltage.

Now and we also know breakdown voltage is 0.72 V 0 is the supply voltage, so this condition is satisfied, so V b can be written as 0.7 to V 0 for maximum power delivery condition is satisfied which is given in the problem, so MRR really becomes proportional to the supply voltage square. So MRR at 40 volts and MRR at 60 volts the ratio of this comes 40 divided by 60 whole square and if you simplify it you get 0.44 as the ratio of material removal rate at 40 volt and material removal rate at 60 volt. Here you can clearly see as you decrease the voltage definitely energy contained in each spark is going to reduce and if energy contained in each spark is going to reduce and volume of material removed is also going to reduce and that is quite obvious from here that at 40 volt a material removal rate becomes 0.44 times of what you get at 60 volt that is MRR 40 becomes is equal to 0.44 into MRR 60.

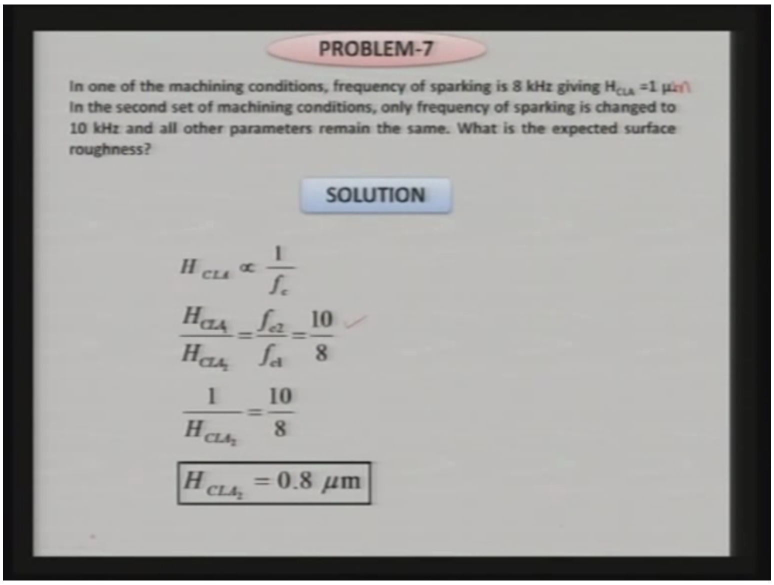
(Refer Slide Time: 48:06)



Next problem in a RC circuit supplied voltage 100 volt, current is 1 ampere and sparking takes at maximum power delivery condition, the pulse frequency is 10 kilohertz. Find the energy content in each spark if every discharge gives 2 sparks only that is the case of multiple sparks EDM. Normally so for whatever we have discussed you assume that only single spark is taking place in each pulses of voltage but here it is assumed that 2 sparks takes place in each pulse that means at 2 places there is the minimum resistance where simultaneous sparking is taking place. In theory theoretical research many people have assumed this kind of assumption and they have analyse the process. However, so far is elemental nobody has been able to prove that more than one spark is taking place at a time.

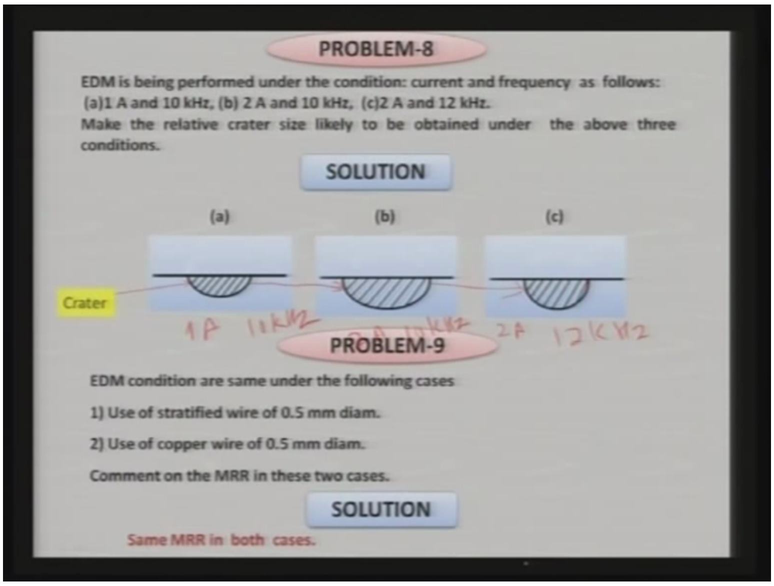
Now given data are as follows, current is 1 ampere, frequency is 10 kilohertz or times becomes 1 over 10,000 seconds cycle time, voltage V b becomes 0.72 of V 0 that is 100 volts given their, so it becomes 72 volt and we know energy is given by Vit, V is the voltage, i is the current, t is the time. So substitute the value of Vit 72 volts current and time t you get 72 upon 10,000, so energy contained in each spark will be equal to E by 2 because there are the 2 sparks in each cycle, so this becomes divided by 2 and you get energy content in each spark will be 3.6 mill watt this is milli. Thus you can calculate what is going to be the energy contained in each spark.

(Refer Slide Time: 50:22)



Now in one of the machining conditions, next problem, frequency of sparking is 8 kilohertz giving H CLA Central line average value RA 1 micro-meter. In the second set of machining conditions only frequency of sparking is changed to 10 kilohertz from 8 kilohertz and all are the para meters remains the same. What is the expected surface roughness value? So we know…solution. We know that H CLA inversely proportional to 1 by f c that is the frequency, so H CLA 1 over H CLA 2 is equal to f c2 over f c1 and we substitute the value of f c2 and f c1 then you can get one over H CLA 2 10 by 8 and if you simplify you will get H CLA 2 is equal to 0.8 micro-meter that is the surface finish. So you can see clearly that with 8 kilohertz the surface roughness value is coming 1 micron and with 10 kilohertz that means frequency is increased and if frequency is increasing then definitely surface finish is going to improve, so you get 0.8 micron as the surface roughness value.

(Refer Slide Time: 51:37)



Let us take another problem quickly is the problem 8. EDM is being performed under the conditions, current and frequency as follows. In one case current is 1 ampere and frequency is 10 kilohertz, in the 2nd case current increases to 2 ampere but frequency remains the same as 10 kilohertz, in the 3rd case current remains the same but frequency increases. Very interesting problem, it says make the relative crater size likely to be obtained under the above 3 conditions. So you can see this is the crater that you are going to get at 1 ampere and 10 kilohertz. Now in the 2nd case the current increases but frequency remains the same, it becomes 2 ampere 10 kilohertz, so now since the current has increase so you can see the size of the crater that is also going to be larger.

Now in the 3rd case the current remains the same but frequency is increasing and we have just seen in the earlier problem that if frequency increases surface finish improves or crater size decreases, so you can compare this here that with 2 ampere and 12 kilohertz the size of the crater should decrease and you can clearly see here that means it is going to give you a better surface finish, so this is very interesting to see how the crater size is varying with the change in the current and with the change in the frequency.

Last problem, EDM conditions are same under the following cases, use of stratified wire of 0.5 millimetre diameter and use of copper wire of 0.5 millimetre diameter. Comment on the MRR and these 2 cases, although I have not discussed this stratified wire, I will discuss in the next lecture but that problem is given over here, the solution say that you will get the same MRR in both the cases, so this particular problem stratified wire I will discuss when I discuss wire EDM in the next lecture. So thank you very much.