Manufacturing Processes II
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Lecture No.39
Electro-discharge Machining

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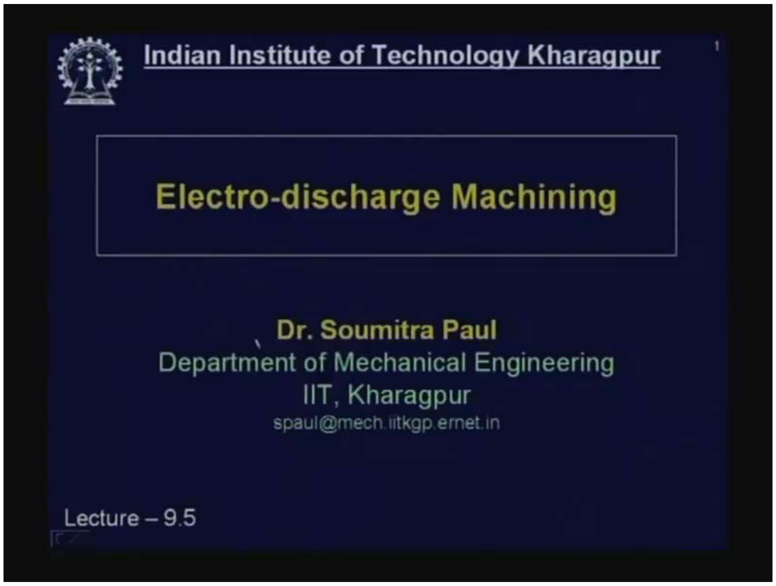

Welcome to the lecture on electro discharge machining. I am doctor Soumitra Paul of department of Mechanical Engineering, IIT Kharagpur. This belongs to the module number 9- lecture number 5. This module is on non-traditional manufacturing. Before going into the details, let us look into the instructional objectives. What are the instructional objectives?

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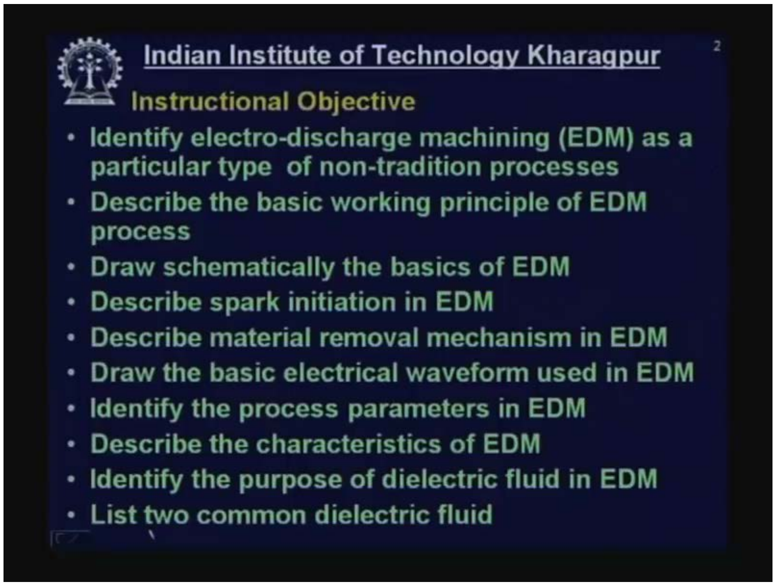

This identifies what you are going to learn? Once you go through this particular lecture. For example, after this lecture you would be able to identify the electro discharge machining process as a particular non-traditional machining process. You can describe the basic operating working principle of EDM. You can draw schematically the basics of electro discharge machining, spark initiation process in EDM is very very important that you would be able to describe in any machining process material removal rate or material removal mechanism they are very important. You can describe that for EDM, electro discharge machine machining process uses electrical energies. So what are the basic electrical waveforms that are used in electro discharge machining that you can draw as well as describe? Process parameters characteristics of EDMs purpose of dielectric fluids. This also you can identify and describe. Analysis is definitely a part of learning process.

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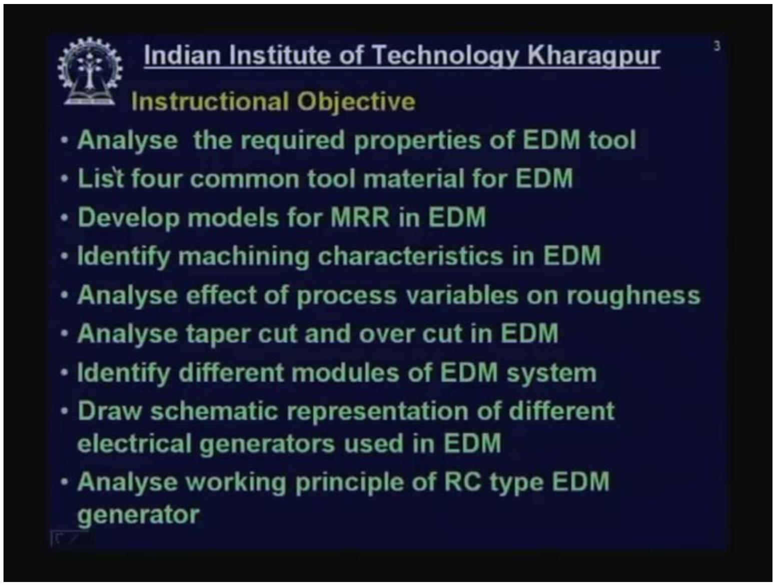

You would be able to analyze the required properties of EDM tools. At least, list four common electrode materials. You can develop models for MRR, identify machining characteristics of EDM, analyze effects of process variables on roughness, taper cut and over cut, identify different modules of EDM system or a machine and draw schematic representations of different electrical generators. So, this is the summary of what you are going learn today. Now let us come to classification of non-traditional manufacturing processes.

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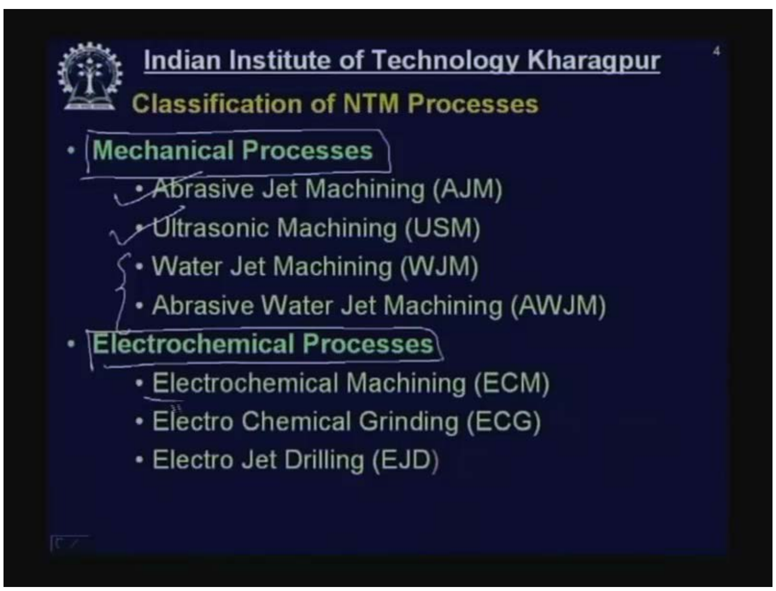

Already you have completed around three lectures in this, but four lectures in this particular module. So you know what is the classification? Let us briefly introduce them once again. You have mechanical processes. You have electrochemical processes. In mechanical processes already we have covered abrasive jet machining, ultrasonic machining as well as water jet and abrasive water jet machining. In electrochemical machining, electrochemical processes we have also covered electrochemical machining. Today we are going to go to another group of processes which is electro thermal processes.

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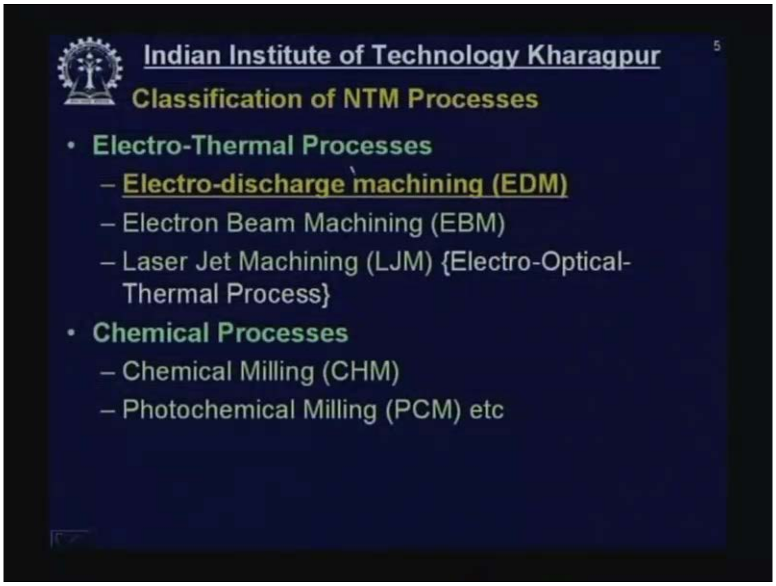

Within this electro thermal process, today we are going to learn electro discharge machining which is also known as EDM. Now let us come to the basic of the process. So this is the schematic. This is the schematic of the process.

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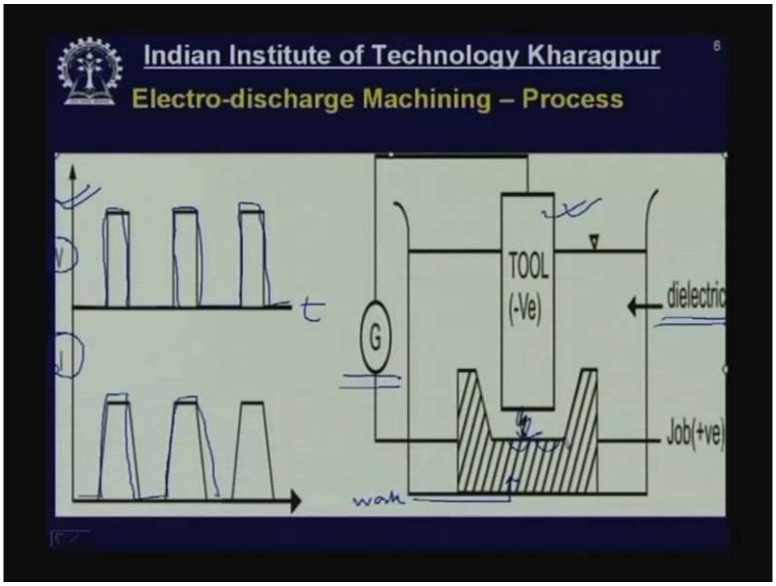

This is my tool. For any machining process, I require a tool and this is my work piece. This one is my work piece say this is a square tool and I need to make a square hole. So this is the tool, this is the workpiece and they are immerged in a dielectric fluid. Typically kerosene is used as a dielectric fluid in electro discharge machining. Now the tool and the work piece are connected to this G which is the electrical generator. This generator produces waveforms like this. So this is my time, this is my voltage v and this is my current I. So with time I will be applying voltage between the tool and the work piece. Once again it would be withdrawn once again it would be applied. So it is almost rectangular waveform and current will also vary in a trapezoidal manner.

Why it would vary in a trapezoidal manner will explain those things later on. Once I apply the voltage, there would be sparking and because of the thermal energy of the spark there would be gradual machining on the work piece and the tool has to be lowered to get a square holed machine. Similarly any intricate shape can be machined using electro discharge machining. Now let us go into the process in a greater detail.

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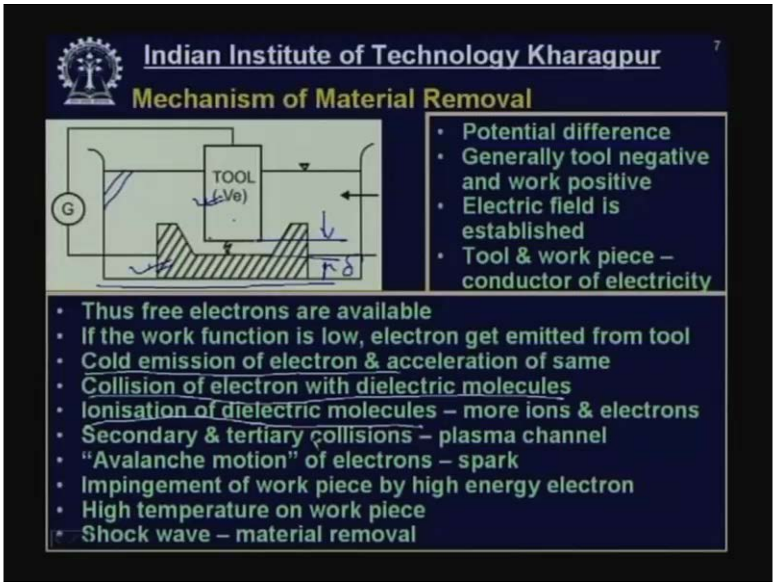

Once again, this is the same schematic that we have drawn here. So what is done? To describe once again, there is a tool and a work piece. I am applying a potential difference between the tool and the work piece. Because of application of potential difference, there would be an electrical field developing between the tool and the work piece. Depending on how much is this gap delta and what is the dielectric constant of the dielectric fluid? If this electrical field is strong enough, it can do something. What it can do? Before that, we need to understand the tool as well as my work piece. Both of then both of them are to be electrically conductive. What do you mean by electrically conductive?

They should have enough amounts of free electrons. Once this electrical field is established, these free electrons would be plucked. Why they would be plucked because they would be experiencing lot of electrostatic force. If the work function of the tool material or the work material of the tool material is less, then these electrons will come out because of the presence of electrical field. Once this electron comes out, they will come out in large numbers. This is called the cold emission. So cold emission of electrons. So after the electrons have been emitted within this particular space, within this between the space between the tool and the work piece, then what can we do? What we can except? These electrons would be accelerated. Why they would be accelerated? Because there is an electrical field and the tool is negative.

So those electrons would be accelerated towards the work piece. They would be accelerated towards the workpiece because that is positive. Now the medium between the tool and the work piece is filled with dielectric medium. So, the electrons will not get a free path. There would be collisions of electron with the dielectric molecules. When collisions occurs with the dielectric molecules, different things can happen by that time if the electron is sufficiently energetic, then it may ionize the dielectric molecule. If it is not sufficiently energetic, then it may lead to elastic or inelastic collision. But, some of the electrons would definitely be energetic enough to ionize the dielectric molecule.

Once they ionize the dielectric molecules, we have more ions as well as more electrons. So initially because of application of potential difference there was a electrical field, because of electric field my tool material being electrically conductive having low work function, cold emission takes place leading to lot of electrons between the tool and the work piece which are accelerated which undergoes collision with the dielectric molecules leading to generation of more ions and electrons. There would also be secondary and tertiary collisions. What are secondary and tertiary? That means the electrons are generated because of primary collisions would once again be accelerated. They would once again undergo collision leading to huge number increase in the concentration of ions and electrons between the tool and the work piece.

This leads to establishment of some thing which is called the plasma channel between the tool and the work piece. Once the plasma channel is established, what is plasma? It is mainly the state of matter where you have it is mostly out of electrons and ions. So in that plasma channel, there would be avalanche motion of electrons that means the plasma channels once it is established, the resistivity would be very less and electrons all of certain will move from tool to the work piece almost in an avalanche motion. At this point of time or that point of time, we can see it. We can see it as a spark. So electro discharge machining is quite often also called spark erosion machining. So this is another name. So what happens of the spark has been initiated or it has been established. The work piece, this is my work piece. This gets continuously impinged by high energy electrons.

So the high, the high energy electrons are having lot of kinetic energy on impediment. What happens to that kinetic energy? The kinetic energy is converted into thermal energy. So you have high temperature on the work piece. This high temperature on the workpiece leads to localized melting and thus we get material removal. Another thing is very very important to understand in EDM. What is that in EDM? We do not apply the voltage continuously. Just a minute, we do not apply the voltage continuously. We apply it in steps why because we do not want an arc to be present. We want sparks. One spark will occur here, may be the next spark will occur here. So that we get the machining throughout the work surface wherever the tool is present. So this is the reason for which we have rectangular waveform instead of a continuous wave for continuous application of potential. Now let us have a look how the standard waveform looks like.

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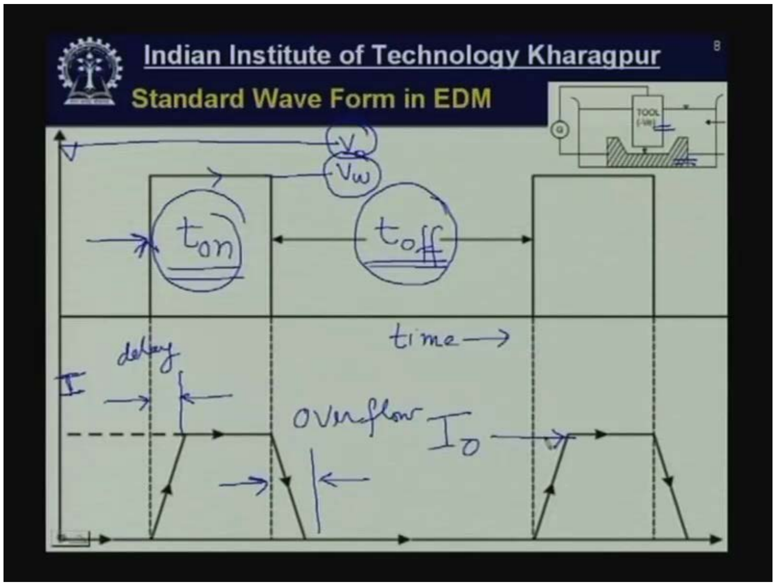

Now this is my standard waveform. This is time; in this direction the upper one this is the voltage and lower one is the current. So, initially what is done? a voltage is applied between the tool and the work piece. This is my tool and this is my work piece tool is negative and I am applying a voltage this applied voltage is called ‘Vo’ or the open circuit voltage when the sparking occurs this is the working voltage ‘Vw’. Now this particular potential difference is not applied infinitely long time. It is infine. It is applied over a time duration which is called the pulse on time and generally denoted as‘t on’. Once again it is applied after sometime and that time is called pulse of time and it is generally denoted by ‘t off’.

So out of this standard waveform, we have started identifying some of the parameters in EDM. What are those? One is ‘t-off’, one is ‘t-on’, one is the open circuit voltage. Another one is the working voltage. Now whenever you are applying voltage between the tool and the work piece. As we have already discussed, there would be sparking initiation flow of electrons which can be grossly said as flow of current. So, the lower one is the current waveform. Here you can note the current attends a maximum value not instantaneously but after some time. This is called the delay. Once again once the wave voltage has been withdrawn the current does not drop immediately to zero. It takes some time to drop to zero.

This is called over flow of current or over travel of current. Thus another parameter or another process parameter comes in which can identify the EDM process which is how much is my maximum current. The level of maximum current which is ‘Io’. So this is my standard waveform and while discussing it, we have also identified some of the process parameter. Now let us go to the next slide where a list of process parameter is given.

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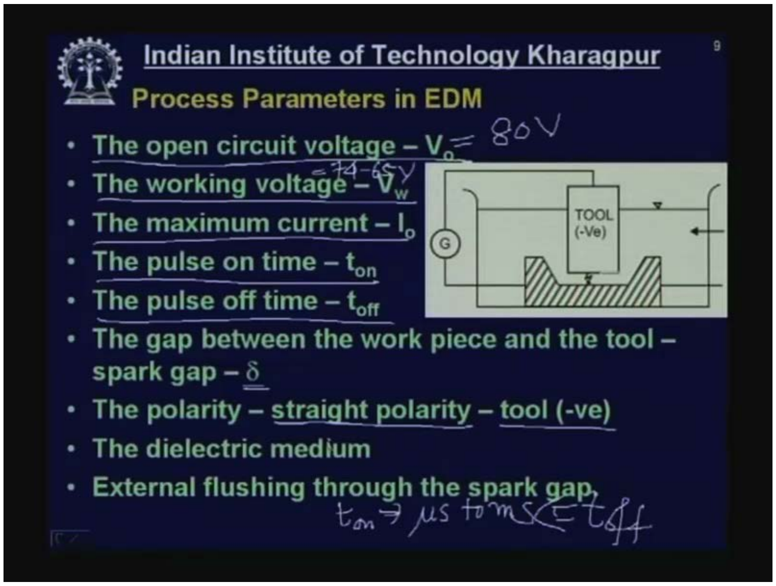

Let us try to understand them. So the first one is ‘Vo’; this we have already applied and already discussed. This is the open circuit voltage. Next one is the working voltage. Typically open circuit voltage is around 80 volt. Working voltage is typically around 74 to 65 volt, then there is maximum current. We have already identified that in the previous slide, then there is pulse on time. Pulse on time ‘t-on’ is typically in microsecond to millisecond. So that is the order pulse of time the range of pulse of time is also similar. So it is almost in the same domain as of pulse on time, then there is another very important parameter that is the gap between the tool and the work piece.

So this is your tool. This is your workpiece between the tool and the workpiece, there is a gap. So that particular gap which is given by delta. Then, while discussing the spark initiation time we have said the tool has to be negative. But, it need not to be negative all the time. If the tool is negative, then it is called straight polarity but there is also possibility of using reverse polarity, then the question comes of dielectric medium. We have already informed you, the dielectric medium could be kerosene or it can be other fluid as well. So depending on what is its dielectric constant that becomes a parameter. Dielectric fluid is not available or it is not static in the spark cap. Dielectric fluid can be made to flow in the spark gap.

So this area is not static. So you can use external flashing technique so that, always between the tool and the work piece, there is reflushiment of the dielectric fluid. So external flushing through the spark gap is also a parameter in electro discharge machining. Now, let us go in to the characteristics of electro discharge machining process. The first characteristics: the process is used to machine any work material irrespective of its hardness.

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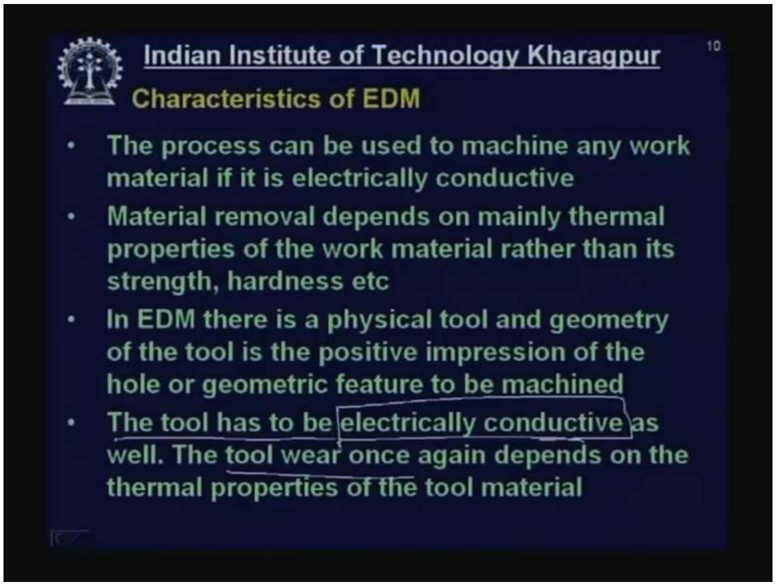

When I am doing a turning operation, we are to some extend respect restricted by what is the hardness of the work material. What is the strength of the work material? But, in case of electro discharge machining, we can machine any material as long as it is electrically conductive. If it is not electrically conductive, then machining under electro discharge machining is not possible. Because, it will not easily leave or provide electrons or feel movement of electrons would be very less and there would be other problems. So this is the first characteristics, second characteristics. Material removal rate or material removal does not depend on the strength or hardness of the work material. Rather, it depends on the thermal properties of the work material. Why because, when the spark is impinging on the work piece, it is generating thermal energy.

So how much melting would occur depends on what is its specific heat. What is its thermal conductivity? What is its density as well as it will depend on what is its melting temperature? So these are all thermal properties, not there strength properties which is much more relevant in case of conventional machining. In electro discharge machining, there is a physical tool. What you mean by a physical tool? As if when you are turning, there is a physical tool. Similarly in electro discharge machining, as will you require a physical tool and the geometry that you are going to impart on the job. It is basically the negative impression on the tool.

So I can say geometry of the tool is the positive impression of the hole or the geometrical feature to be machined. Is there any process where I do not require a physical tool yes we have already gone through such processes. Say for example; abrasive water jet machining there I have a water jet. I do not have a form solid tool but in electro discharge machining I have a physical tool. Another non-traditional process which I have already gone through is electro chemical machining. There also I require a physical tool. So, there are processes within non-traditional domain where as at times, we require physical tool at times there is no physical tool present. Another very important thing that we have already discussed, the tool has to be electrically conductive.

If it is not electrically conductive, free electrons would not be available. Typically there work function would be much higher. So you need to apply much higher voltage to pluck electrons during the cold emission phase. So it is better that it is highly electrically conductive. Once again, the tool wear does not depends on its physical strength. What is its young's modulus? What is its hardness or ill point? The tool wear does not depend on that it depends on what are its thermal properties? Something very similar to material removal depends on the thermal properties of work material. Now let us go into the other characteristics of electro discharge machining.

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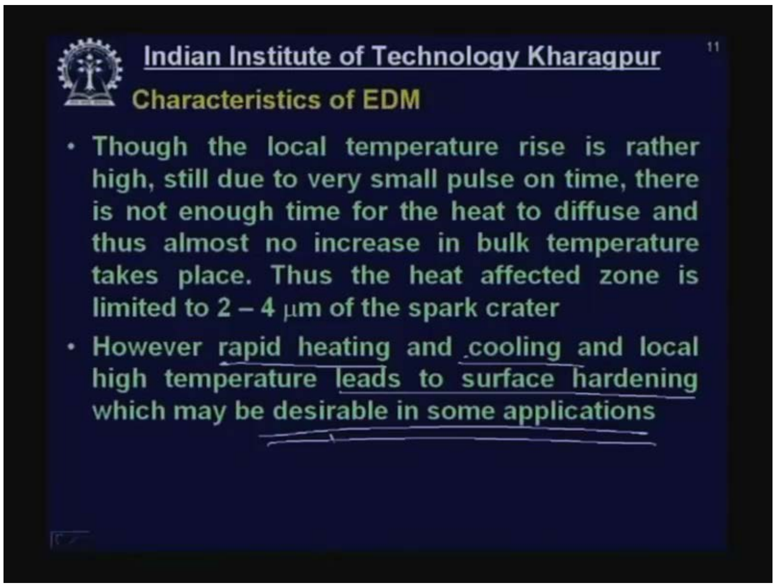

Within the tool material whether it is tool material or work material because of intense heating intense because the electrons are very high energetic. So the local temperature rise would be very very high, but the pulse on time that we have already discussed is in microseconds or milliseconds. Thus, whatever heat is generated at the site of impact of the electrons, that heat does not get enough time to diffuse in the work piece. This is advantages what happens? Thus, there is very less increase in the bulk temperature and typically in any thermal processes, you have lot of heat effected zone like in welding, in oxy acetylene flame cutting, but in electro discharge machining though it is a thermal process as the one time is very very less, heat affected zone is very limited typically to two to four micron of the spark crater.

So this is very advantageous characteristics of electro discharge machining. However though the temperature rise is local, it occurs with a rapid heating and the cooling rate is also very very high. It may quite often lead to the local metallurgical changes and surface hardening, quite often this surface hardening is desirable. Not in all the applications, but in quite a lot of applications, this such kind of surface hardness hardening would be desirable such a way, then he can get benefit out of this particular characteristics. Now, let us come to some quality parameters.

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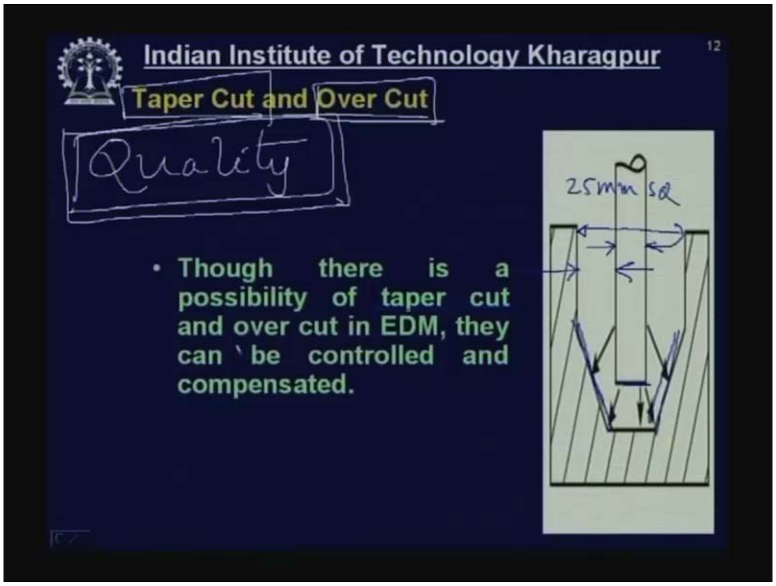

This is very very important. So this particular slide talks about the quality issue in electro discharge machining, one is called taper cut. Another one is called over cut. Do you want them? We do not want them. But, unfortunately when I am doing an electro discharge machining, then though it is undesirable there would be some amount of tapering effect as well as if say, this is a twenty five millimeter square. Still I will get a hole which is much which is definitely wider than this. So this is called over cut and this taper nature which occurs near the end of the tool or the active surface of the tool gives you taper cut. This taper cut as well as over cut are not desirable and to some extent they can be controlled and if they cannot be controlled, there can be look up table where I can see how much over cut occurs and I can compensate for that while designing the tool. Now another very important medium is the dielectric.

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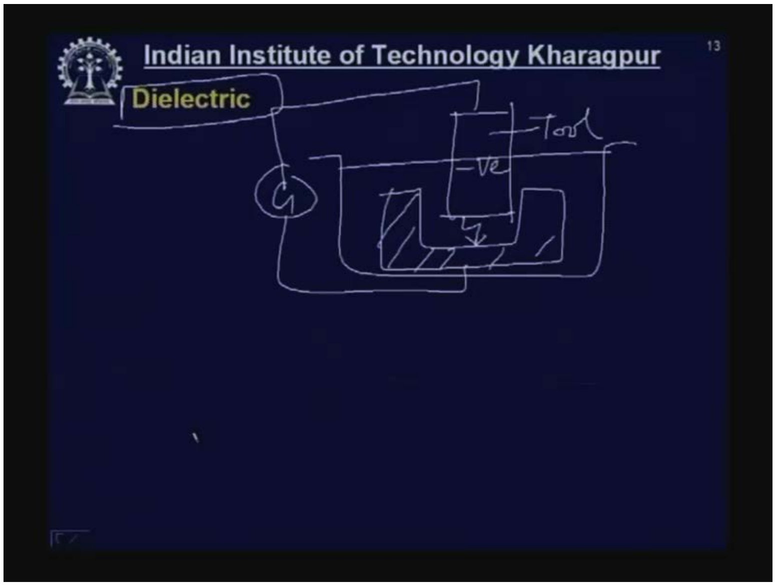

Why? Because I have a tool, I have a tank, I have a work piece. Between the tool and the work piece, I am applying an electrical pulse and because of that there is a spark and machining but the whole thing is immerged within the dielectric medium. Thus what is its role? Let us look into that.

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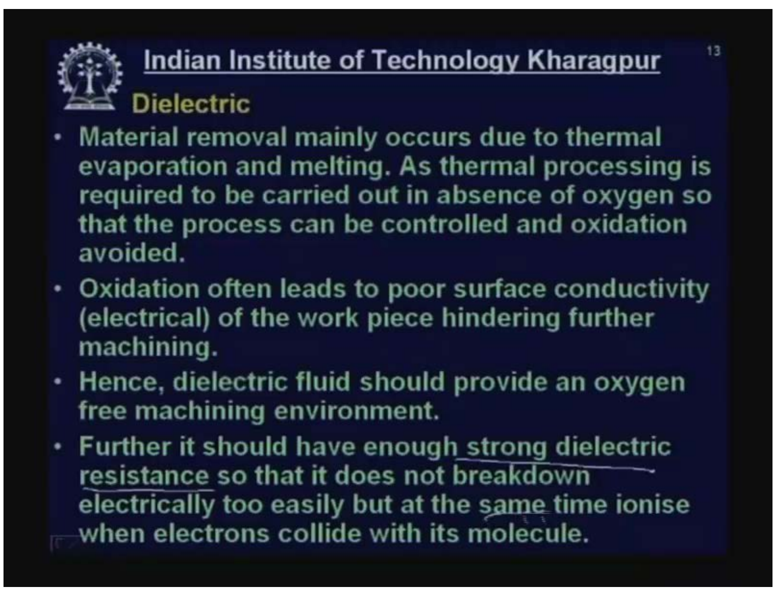

Material removal as we have already discussed mainly occurs due to thermal evaporation and melting. So, if such melting occurs in presence of oxygen will get oxidation. Now oxidation at times is good for us, at times it is not good for us. If some one is interested in rough machining like oxy acetylene flame cutting, then oxidation is good for us. But, electro discharge machining is a secondary machining operation. There oxidation is not at all good it is undesirable. Why because there is another problem. Oxidation when it will occur on the job surface we lead to a oxide film which will reduce the surface electrical conductivity and this will hinder the machining process because the spark will not be stable the total efficiency of the spark would not be utilized because there is a reduction in the electrical conductivity.

So in electro discharge machining oxidation has to be prevented and this is done by the dielectric fluid. So dielectric fluid should be such that it is divide of oxygen and it should provide and oxygen free machining environment. Further, it should have a strong dielectric resistance or dielectric constant. So that when we apply a potential difference when this is my tool, this is my work piece. When I apply a potential difference, it does not break down very easily but at the same time it should ionize. If it does not ionize, I do not have a plasma channel I cannot have a spark. So it should have to conflicting properties a need it should have strong dielectric resistance at the same time, it should ionize. It should not be such that, it does not ionize at all. So, we are continuing with the properties which are expected of the dielectric or characteristic which are expected of the dielectric.

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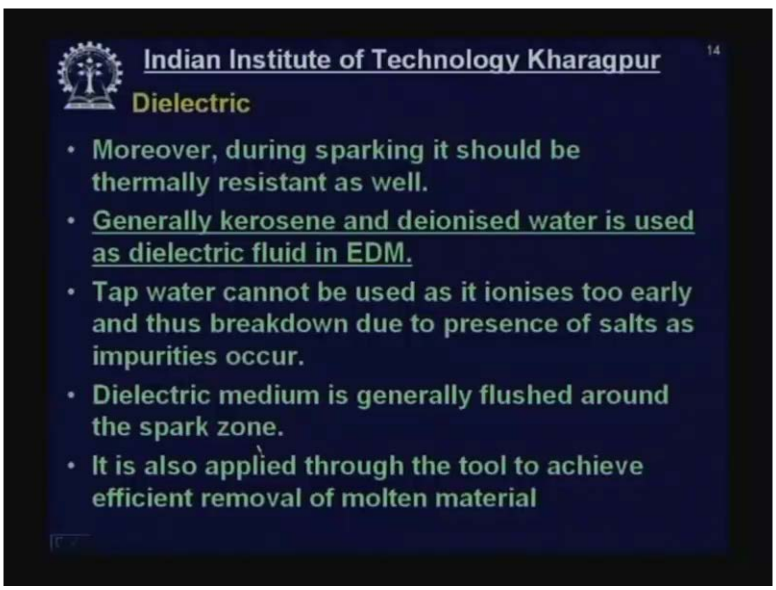

Once again, this is the tool. This is the work piece and there is a spark. This spark is rather violent from the thermal point of view. So during such sparking, my dielectric should not break down. It should be thermally resistant. It should not dissociate because of high temperature of the spark. Generally, in electro discharge machining kerosene is used as well as deionized water is used. You may say why deionized water? Why not tap water? Unfortunately tap water would be having contaminants like salts. So it will ionize too easily and break down. So tap water cannot be used. It does not have enough dielectric constant. It is having salts in it. So it ionizes too easily. So it is not good for electro discharge machining. So two of the ideal candidates for dielectric fluid are kerosene and deionized water divide of salts. This we have already talked generally between the spark gap the dielectric medium is flushed continuously. So that there is no stagnation, it replenished all the time. It can also be applied through the molted. It can also be applied through the tool. How can it be applied? Say for example;

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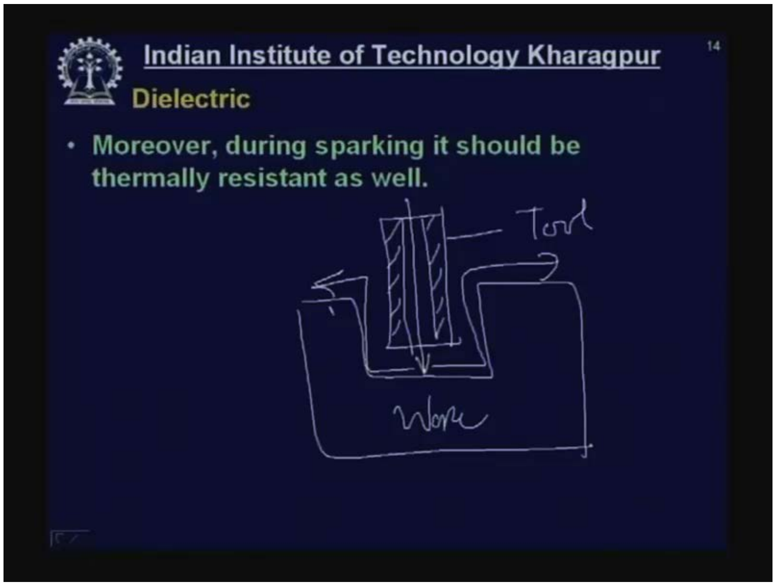

I have a tool like this where, there is a hole at the center and I am making a square hole within the work piece. This is my work piece and this is my tool. So the dielectric can also be flushed through this particular hole. This is a very efficient way of flushing the spark gap. So these points we have already covered. Now let us go into another important aspect which is tool material.

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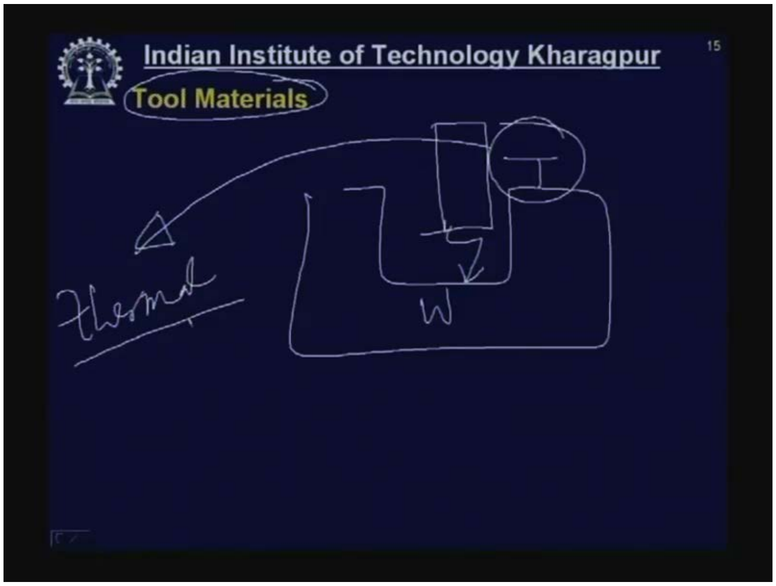

Once again let us draw the schematic. This is my tool, this is my work piece. So definitely the tool material properties are going to affect the process. We have also indicated earlier what are those properties? They are mainly the thermal properties. So now let us come to the point wise discussion.

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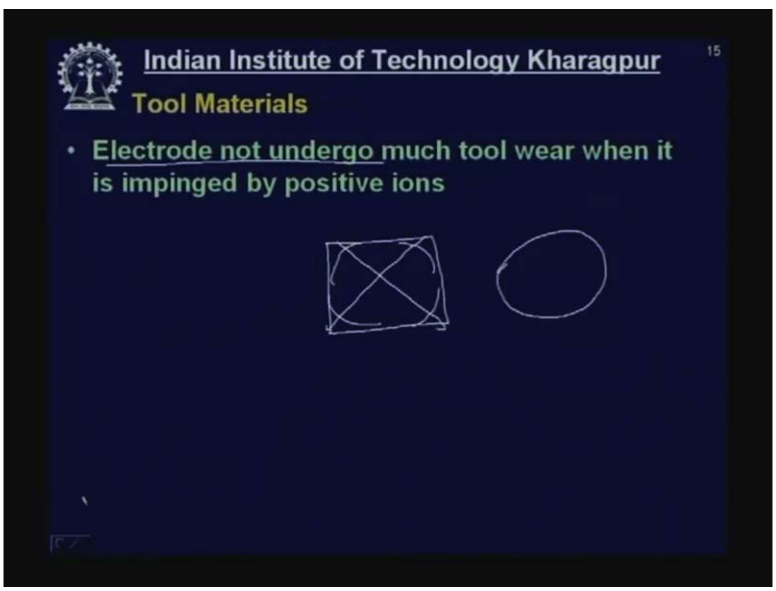

First and foremost, electrode should not undergo much tool wear. Why? I am interested in making a square hole. This is the top view; if it undergoes tool wear I may get an elliptical hole because it has worn out over here. So it should not undergo in new tool wear when it is impinged by the positive ions from the plasma.

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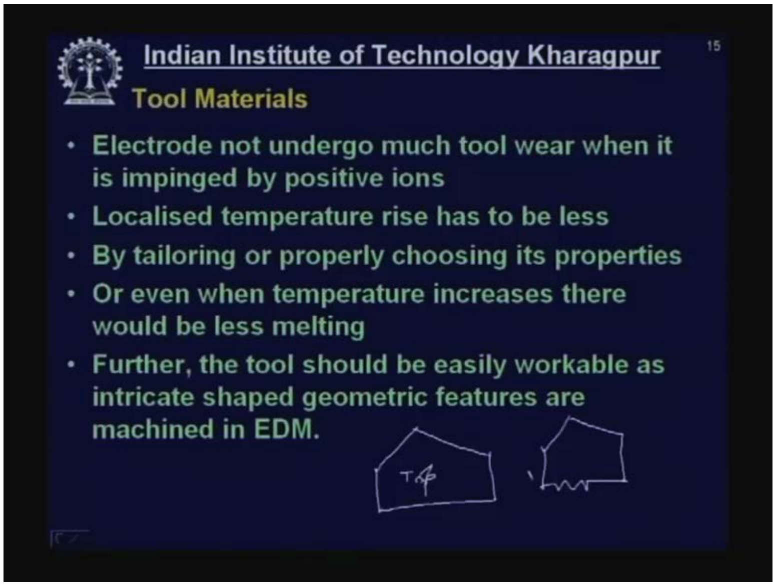

There would be localized temperature rise, but somehow we have to restrict this. So that it is very less or it is manageable. How can you do that? We can do that either by tailoring or properly choosing the tool material or even if the temperature rises high, there should not be any melting. So, I have to choose my tool material properties accordingly. So tool should be typically electro discharge machining is used for drilling complicated holes of different shapes. This is a top view say I want to drill a pentagonal shape or a complicated shape like this. So that shape has to be initially imparted on the tool or else I cannot do it. So intricate shape geometric feature we should be able to machine on the tool. So tool should also be machinable under conventional machining. It should be highly machinable, then comes the physical properties like electrical and thermal, it should have high electrical conductivity.

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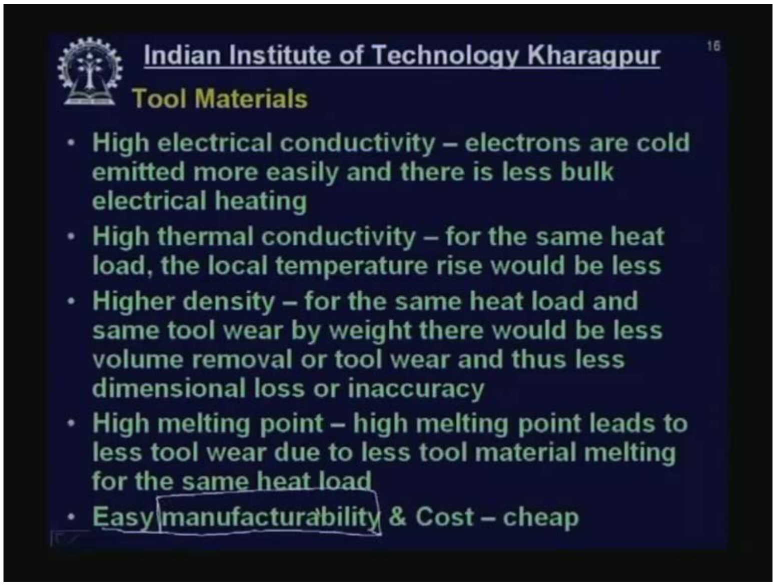

If it is not having high electrical conductivity, then electrons will not come out easily during cold emission and there would be unnecessarily bulk heating because it is going to carry a lot of current. So, if its conductivity is poor, there would be an unnecessary bulk heating of the electrode which is once again not desirable. It should have high thermal conductivity. Why? Why it should have high thermal conductivity? If it is having high thermal conductivity, for the same heat input, it would be able to conduct away the heat from the zone where it is being impinged by the ions. Thus thermal conductivity if it is high local temperature rise will be less which is good for the tool. It should have high density. Why because for the higher density, its dimensional loss would be less.

If the density is higher for the same weight loss, its dimensional loss will be less and we are interested in reducing the loss of dimension because I want to drill a hole with a particular size and shape. So as long as the dimensional deviation is less, that is acceptable. How can I do that? By tailoring the tool material property which is having higher density. It should have high melting point even after playing with these properties if I cannot manage, then the temperature is going to rise. How can I counter that? If my tool material is having high melting point, then definitely because of temperature rise there would be less amount of erosion of the tool. Once again it should be easily manufactured. Its machinability or manufacturability should be high and cost should be chip because you require lot met lot of tools in EDM because it wears out and it has to be re machined once again. Now what are the tool materials which can be used in EDM which satisfies all those requirements.

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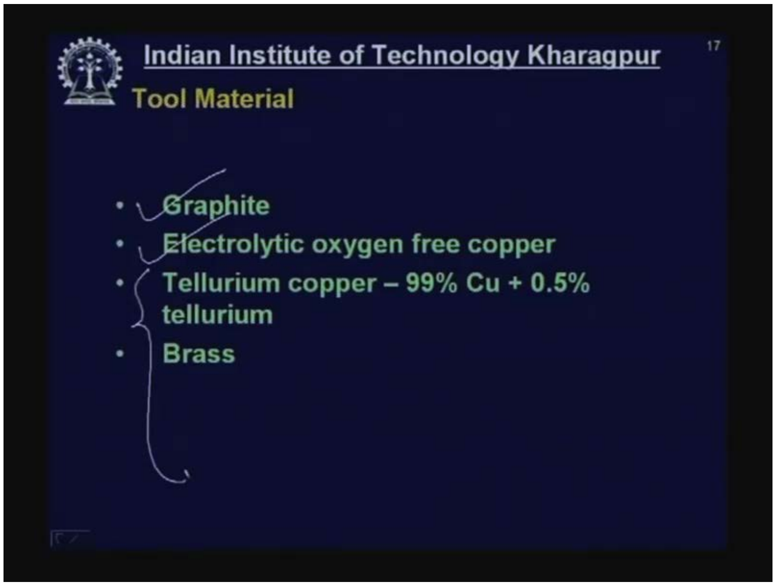

Now all those requirements are very difficult to satisfy. So some of the tool materials are graphite, oxygen free copper, oxygen free copper would be having high density. It is having high thermal conductivity. Its electrical conductivity is also high. See it definitely satisfies quite a few of the properties. Unfortunately, it is costly but it is really difficult to find the tool material which satisfies all the properties. So, graphite is a good choice. Oxygen free electrolytic copper is another choice. There are other work materials are as well like brass, tellurium copper which are improvements which are coming up day by day. Now let us go into the modeling of material removal rate in electro discharge machining.

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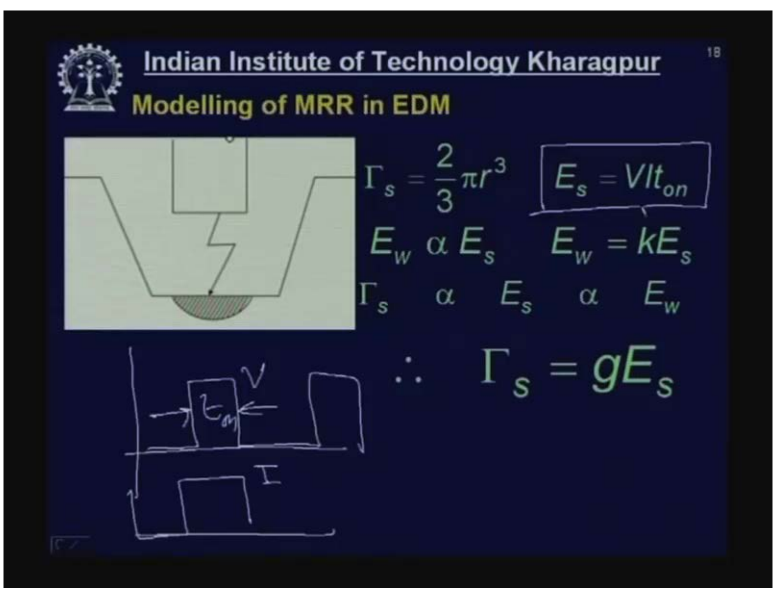

Why we need to model? If you can develop a model, then we can easily understand without going into rigorous experiment what is going to happen if we change the parameters? So what it shows? Schematically it shows this is my work piece and this is my tool. This is a particular spark, due to sparking, there is a crater formation. We are assuming this crater to be hemispherical. If this crater is hemispherical, how much is the volume of the crater? two third pi r cube, that is what we have written. Gamma s volume of the crater is two third pi r cube.

How this crater is formed? This crater is formed due to one particular spark. Is it somehow related to spark energy? Is it somehow related to spark energy? Possibly yes; so let us try to estimate, how much is my spark energy? Spark energy is v into I into 't-on'. This is my voltage pulse which is 'V'. During voltage ideally, this is my current pulse they are on for a time t 'on'. So spark energy is VI into t-on. Now the energy available at the workpiece is not the total of the spark energy because the work piece is impinged by electrons, tool is impinged by ions. There is some heating of the dielectric medium. So workpiece energy is proportional to spark energy. It can be assumed to be linearly proportional. Now we can also say volume removal or material removal in a single spark is proportional to the spark energy which in turn is proportional to the energy available at workpiece or in other words I can say material removal in a single spark is proportional to spark energy which can be re-written in this manner.

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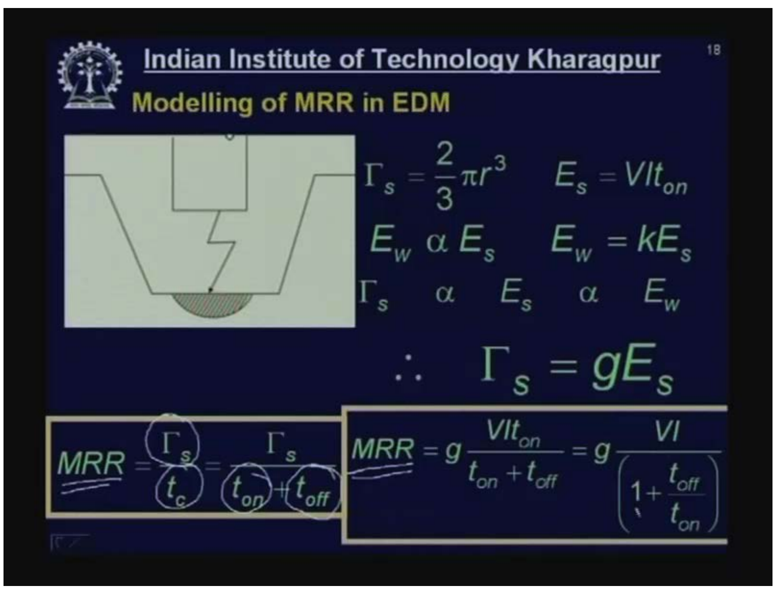

Material removal rate is the volume removal in a single spark divided by total time of spark. How much is the total time of spark? Is it only t on? No, it is the cycle time. So it is t on plus t off. So if I simplify, I get an expression of material removal rate as g times vi divided by one plus t-off divided by't-on'. So this equation is very simple equation which has been developed with assumptions but this has been found to be a very very indicative equation. If I increase I, I get higher material removal rate. If I increase the potential difference, I also get a higher material removal rate. If I increase't-on' I get a higher material removal rate. So these are very very indicative. If I reduce the cycle time by reducing t-off here, I also get a higher material removal rate. So, I can predict what would be my nature of material removal which gets related to four of my very important process parameters. Now let us go into product quality issues; product quality is another important aspect. One aspect is how fast can I machine find material removal rate another one is product quality.

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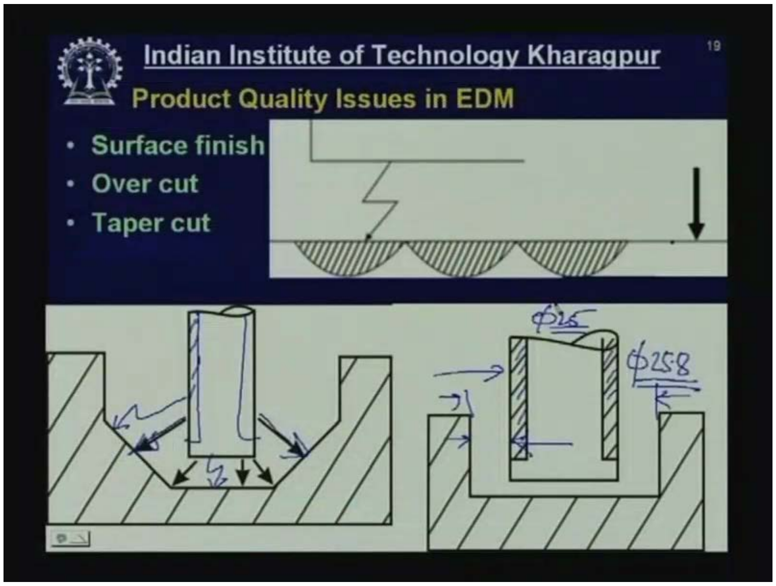

I can machine very fast but whatever I am going to machine are they going to be accepted by the industry. So I have the issue of work surface finish I have the issue of over cut and also have the issue of taper cut. What it shows in this particular diagram? It shows, this is my tool surface this is my work surface. This is the first spark. This is my first spark where seconds spark is going to occur. I do not know what I need to model it? So I will assume as if it occurs just beside the first spark. In practice, it never occurs just for modeling sake, I am assuming that third spark as if occurs here. So, thus I can say as if this one is the generation of the surface.

So this is my surface roughness 'hm' because ultimately I am going to get a surface which is like this. Can I model this 'hm'? Can I relate this 'hm' with something else? Yes, I can do that, will come into that taper cut. We have already explained earlier. So this is the taper cut part of it and this is the over cut part. Now can I prevent taper cut? Yes, I can prevent taper cut. How do I prevent taper cut? By insulating the tool material here, taper cut occurs because there is sparking on the side of the tool as well. There is sparking here. But, I cannot prevent a spark to occur from the side. How can I prevent it? I will coat the side of the tool with insulator which I have done here and immediately taper cut can be controlled. Can I avoid over cut? No I cannot avoid over cut.

How can I tackle it? I can tackle it say this is a 25 millimeter diameter tool on experiment I find out the diameter of the hole I am getting 25.8 millimeter. Thus I know if I use a 25 millimeter tool, I will get 25.8. If I am interested in getting a 25 millimeter hole, possibly I will use 24.2. So this data bank is required to compensate for it. It cannot be prevented but by tool design it can be compensative. Now let us come to the modeling of surface roughness:

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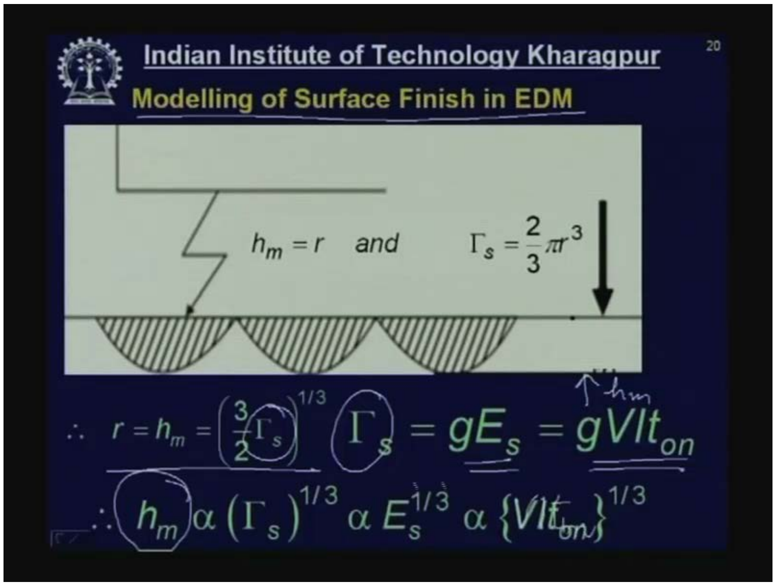

So modeling of surface roughness; so, as we have already said, this is ‘hm’. ‘hm’ is equal to ‘r’. So ‘hm’ can be related to gamma s which is volume removal in a single spark. So gamma s is related to spark energy. So, this is my spark energy and ultimately I can see surface roughness is proportional to V with a power of one third I with a power of one third and ‘t-on’. So both all three of them, it is however is not a function of t-off. As it is coming out of this one, this is a very simple model. From this model, surface roughness is getting related to VI and ‘t-on’. This is getting related to VI and t-on with a power of one third or 0.33. Now, let us go into the issue of productivity and quality at the same time.

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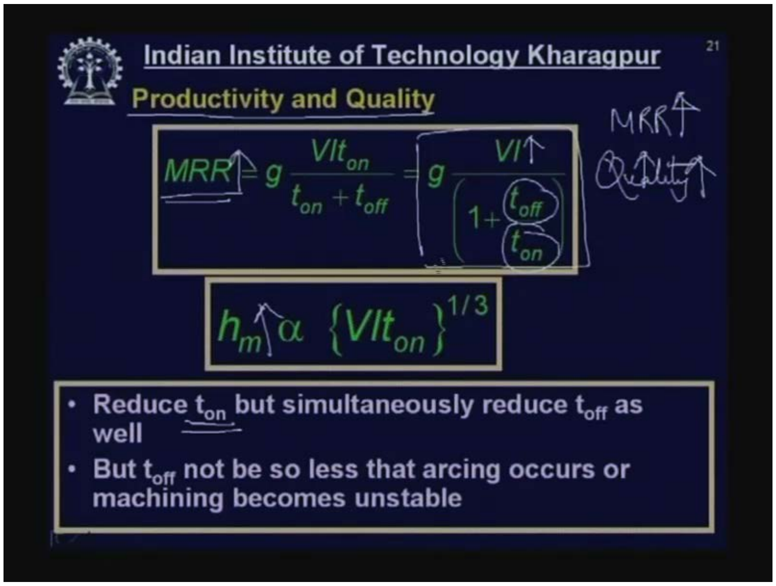

I want to use, I want to machine with as much material removal rate as possible with high quality as well. I do not want to sacrifice quality. How can I do it? This is the expression of material removal rate. So if I increase material removal does go up but my surface roughness also goes up. So, what do I do? I have to reduce,'t-on' but simultaneously have to reduce t-off. So that I can reduce MRR, I can have high quality without sacrificing material removal rate. Straight forward, if you want to increase if you want to reduce hm you have to reduce any three of them, reduction of any three of them leads to reduction in MRR. So what is your intention? I will try to reduce MRR. Sorry I will try to reduce surface roughness but I will not sacrifice material removal rate. How do you do that? Reduce 't-on' but simultaneously reduce 't-off'. So that this particular ratio is remaining same. So you can reduce 'hm' but MRR remains same. But, there is a limit to which this can be reduced because if you reduce too much, there would be unstable sparking.

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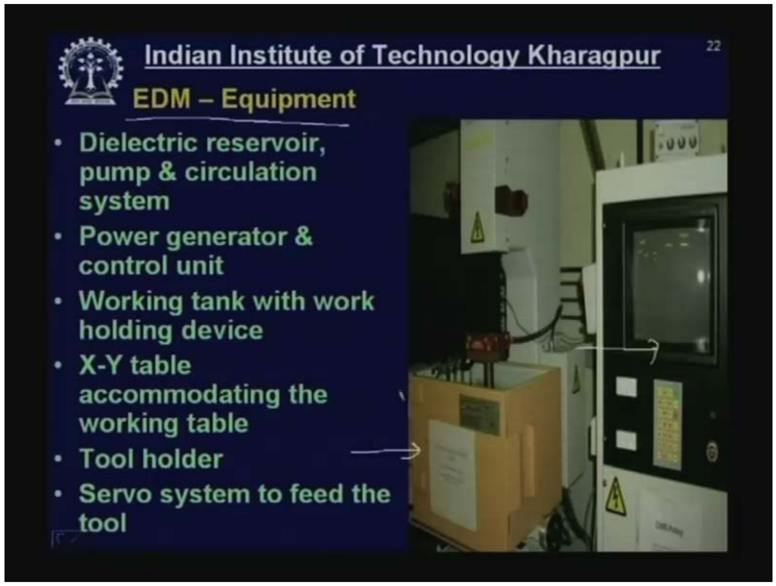

So this is the photographic view of the equipment what you can see? This is your tank, this is the controller. Power generators as well you have the tool holder here. This is the servomechanism with which the tool comes down. So, this is a photographic view of an EDM machine. Now as we were seeing.

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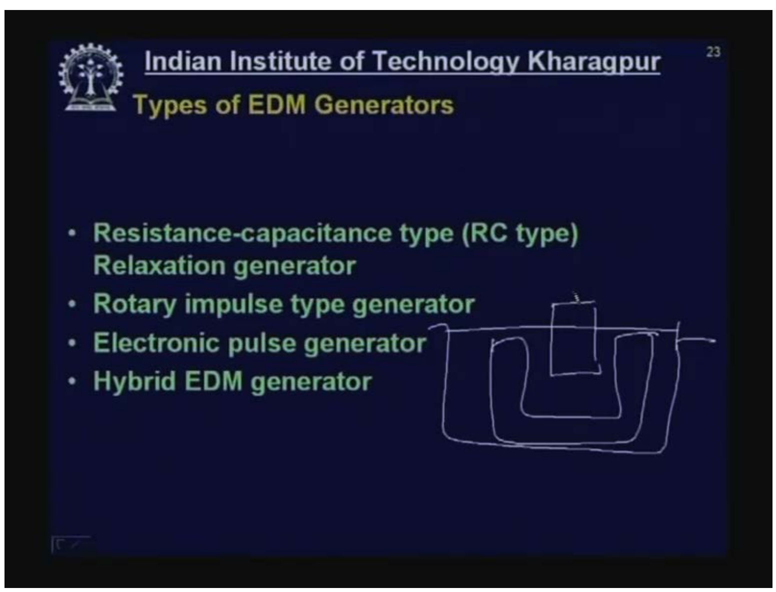

I have a tool, I have a workpiece which is immersed in a tank and they are connected to a generator. So, now we are going to discuss types of EDM generator which are used. There are different types of electro discharge machining, EDM generator. But the very basic one which is still used, very productive in the machining, and in the industrial environment is RC type. Other than RC type, we have rotary impulse type electronic pulse generator hybrid electronic pulse generator. So we are going to see schematics of these the circuit diagrams of all the force and later on we are going to analyze the working principle of RC type generator.

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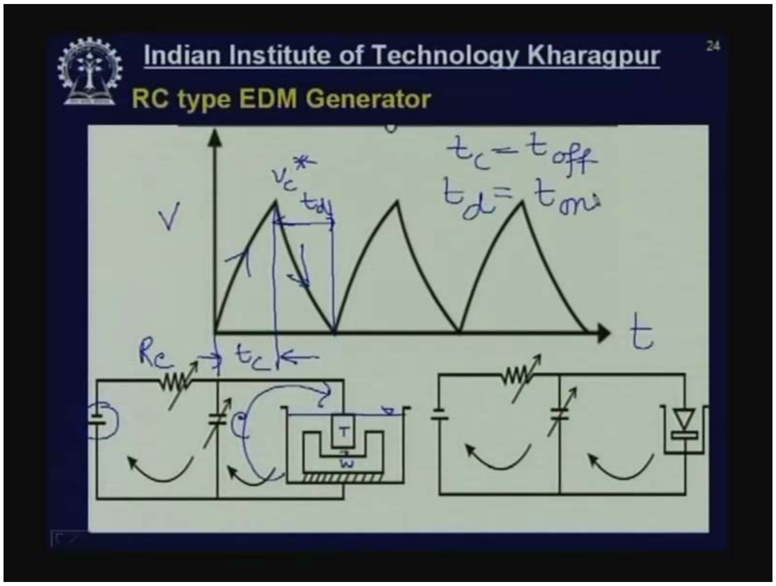

So what is there in a RC type generator? I have a source of emf, I have a source of emf here. I have a charging resistor RC, I have a capacitor c and this is as you can see the tool workpiece in immersed in the dielectric medium electrode. This is the EDM machine. This one is the same thing. Here, the EDM has been represented with a symbol as if it is diode kind of thing. So what happens? When the potential difference is applied, this is my voltage and this is my time. Gradually, the capacitor gets charge to a value of 'vc star'. Once it gets charge to that value, then once again it is discharge. So typically, this is your charging time 'tc' and this is your discharging time 'td'.

Now charging time, during charging EDM is not going on. So that is your off time. During discharging, the current is flowing through the EDM machine through the spark gap. So this is your 't-on' time. So it works in a very simple principle. I gradually charge the capacitor which gets discharge through the machine. Now, I have a rotary impulse generator with a rectifier.

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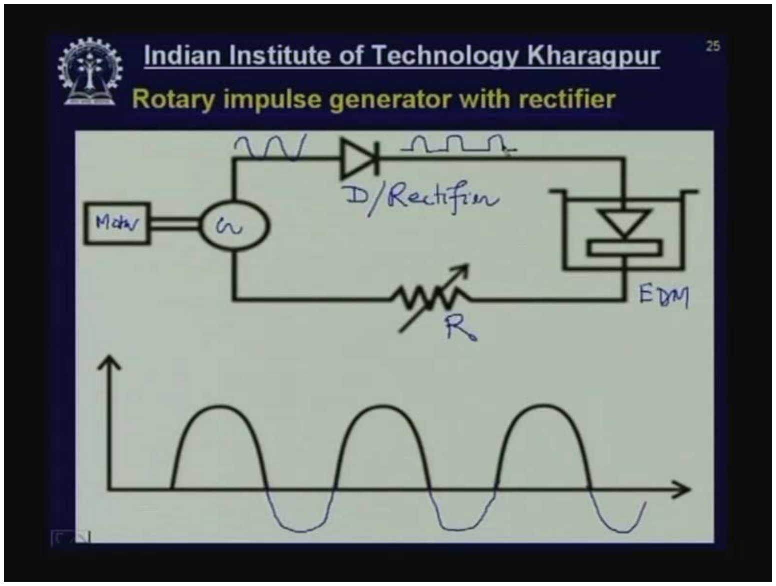

This is my diode or a rectifier. This is the EDM machine schematic representation. This is resistance, this is a variable resistance. What is this this is a motor and this is a generator. So once I run the generator with the motor it is going to generate a sinusoidal wave. Now when this sinusoidal wave passes through my diode only the positive part would be allowed, the negative part would not be allowed. So what we get once it passes through is a pulse like this where I have only half cycle present.

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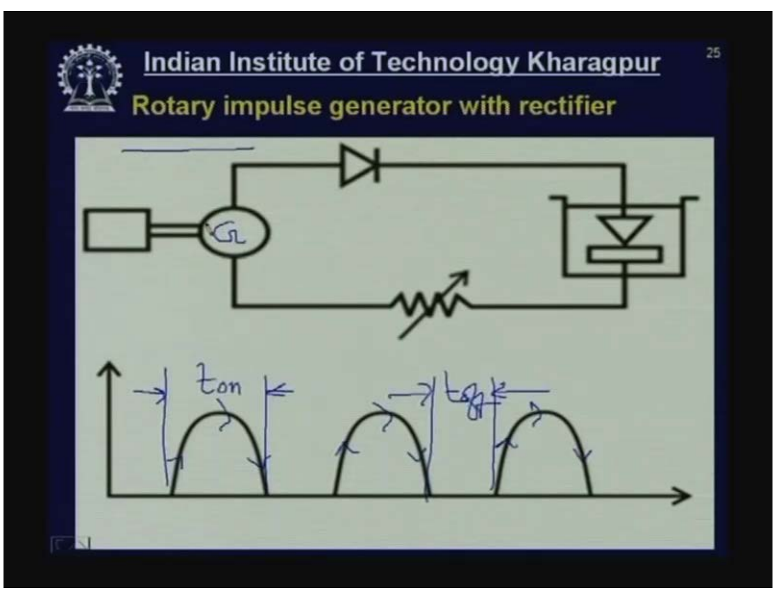

So during this half cycle I have machining which goes on. So once again, this would be equivalent to‘t-on’ and during this time, there would not be any machining. This would be equivalent to ‘t-off’. So this is a rotary impulse generator. This is a very simple generator. However, here t-on and t-off would be both same. Because, this is nothing but an electrical generator. Now we are coming to an electronic pulse generator.

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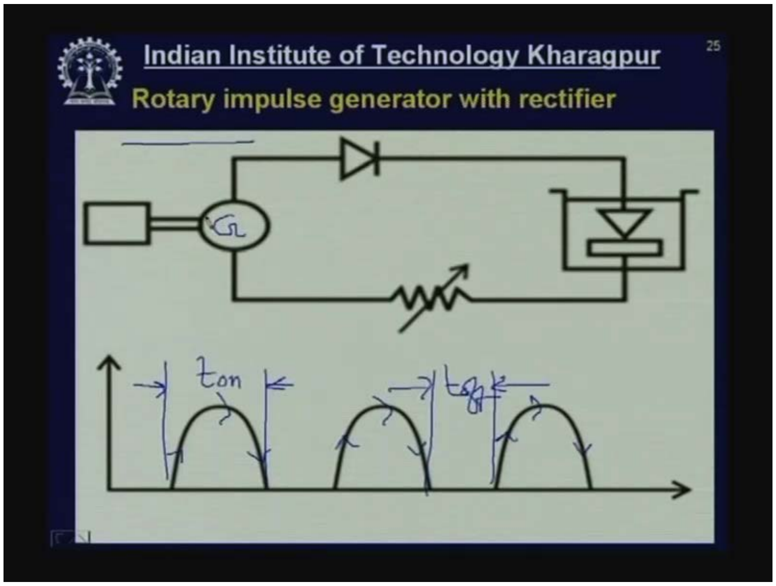

So what is there? There is a source of emf which is providing a steady voltage and this is an electronic switch. This is an electronic switch what it does? On its base I am giving a pulse like this. This pulse does not have enough power. This only drives when the pulse is positive. When there is a positive part of it, then it allows this particular emf V zero to come out. When it is off, it is also off. So basically this pulse is triggering, this particular emf source. Thus you get pulse from like this where this is t-on and this is t-off. What is the advantage of this as because it is driven by this electronic pulse generator. At the base of the switch, I can have any value of t-on and t-off whatever I desire in case of the previous one here.

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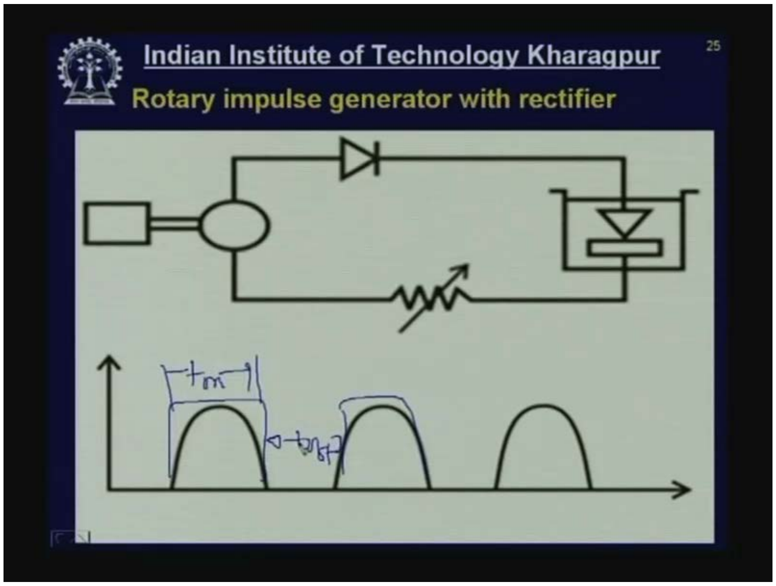

First of all, I do not have rectangular pulses and moreover t-off and t-on they as same which is not good. I do not have any controlled but here I have lot of control. So this is a good generator which is use quite often. Now we are going to discuss a hybrid generator.

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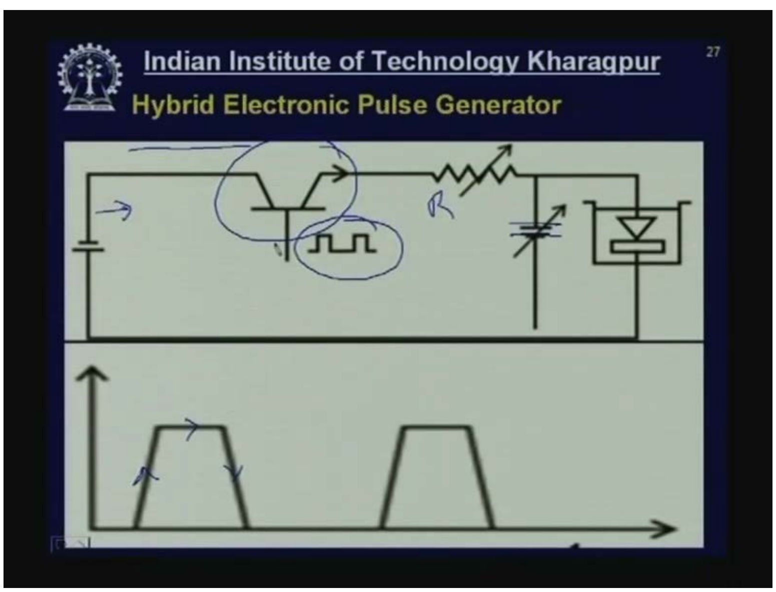

How is it different from standard electronic generator? In a hybrid generator, using the switch using the electronic switch and a standard emf source I charge up resistor using a charging capacitor and that discharges through the EDM machine by properly controlling the RC values and the switching circuit. I can get a nice trapezoidal waveform which is much better than the square waveform as well. So most of the industrial machines nowadays are fitted with either hybrid type electronic pulse generator or still there fitted with RC type EDM generator.

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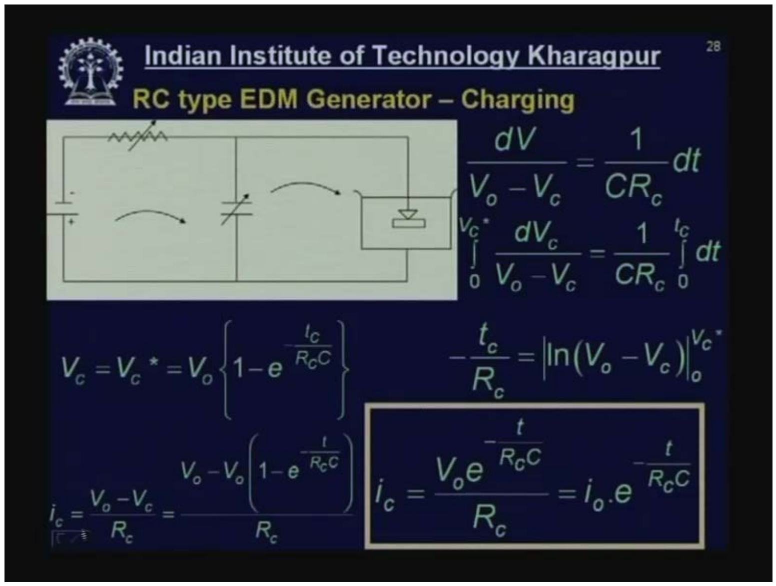

So now we are going to analyze the working of the RC type EDM generator. As we have already indicated, in a RC type EDM generator there is a charging phase and there is a discharging phase. So initially we will discuss about the charging phase. During charging what is happening this capacitor is getting charged is not it. So how is it getting charged? It is getting charged at any instant of time, this is V-zero and at any instant of time, this is Vc which is varying. Thus I can write as because this is a capacitor dv dt into c would be V zero minus Vc by R. This would be the current which is modified here to get this particular expression. Now this has to be integrated.

So this is integrated at time t equal to zero. This was zero. So it is integrated from zero to zero and the upper limit is Vc star at time ‘tc’. So we get this particular expression after integration which can be once again modified or simplified to get an expression of the current, charging current ‘ic’ and ultimately my charging current ‘ic’ would be io times e to the power minus t by RC into c. This RC is the charging resistor value. This is the capacitance value and ‘io’ is the current which would be achieved when t equal to zero that is the maximum current. Now let us go into the discharging phase.

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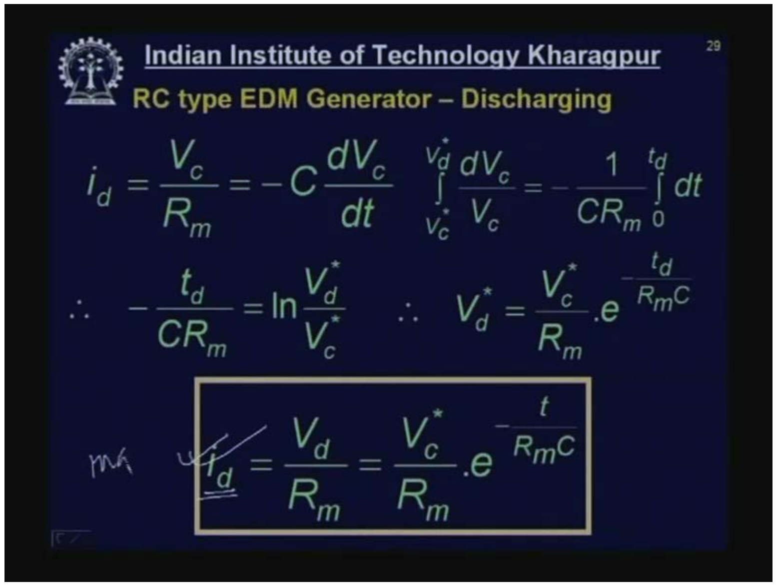

As we said there is charging and discharging. During discharging phase, this capacitor is at a value initially at a value of Vc star and it is discharging to this id. The machine would having a resistance R. So how can we see that here? ‘id’ is given ‘id’ is given as a ratio of voltage by the machine resistance and this is the coming from the capacitor side. So on integration, what we will be getting is the expression of ‘id’ or the discharge current. So this discharge current is basically the machining current. This flows through the EDM machine. The charging current does not flow through the EDM machine. So this is my discharge current. Now let us see the EDM wave form from a RC generator.

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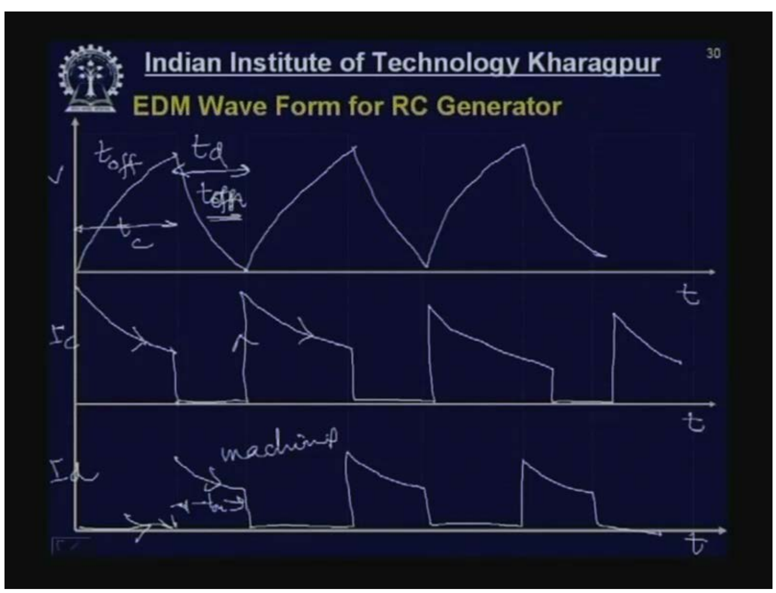

So, this is the grid, this is time, this is time, this one is time, this is voltage. This is charging current. This is discharging current. So during charging, what happens? Voltage gradually increases and during discharging, it decreases. So charging increases, decreases, increases, decreases. This particular one is ‘tc’ charging current which is equivalent to ‘t-off’. This is ‘td’ discharging time which is equivalent to ‘t-off’. This is my charging current. Initially my charging current would be high, then it goes down. Then it become zero because now it is discharging. Once again, it varies like this. So this is my charging current. Can you see? Sorry, this is t-on. During on time, charging current is not there. Discharging current on the other hand would be something like this. Discharging current on the other hand would be something like this. So, this is my machining current and this is on during the t-on phase. Now, let us go into the cycle time and frequency.

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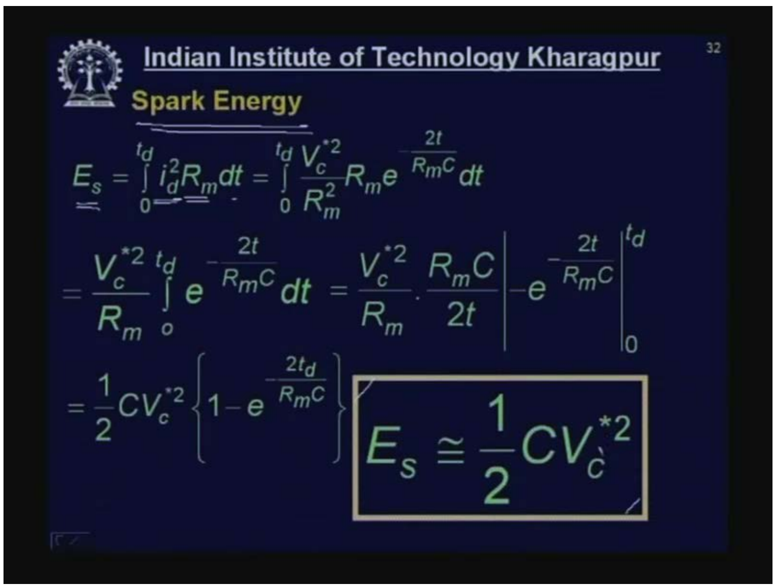

So cycle time and frequency they are important to find out the expression for ‘tc’ and ‘td’ you can find it out using these two that happens when Vc star is around 0.716 time Vo. This occurs when maximum power output occurs. So frequency would be one upon tc plus td. So, with this we can determine how much is the frequency in EDM using RC type generator. How much is the spark energy? Spark energy can be determined as Es which is discharge time square Rm into dt with proper integration. You will get almost the spark energy equal to half cv square or cv star square. Now, let us come to the summary of today’s lecture.

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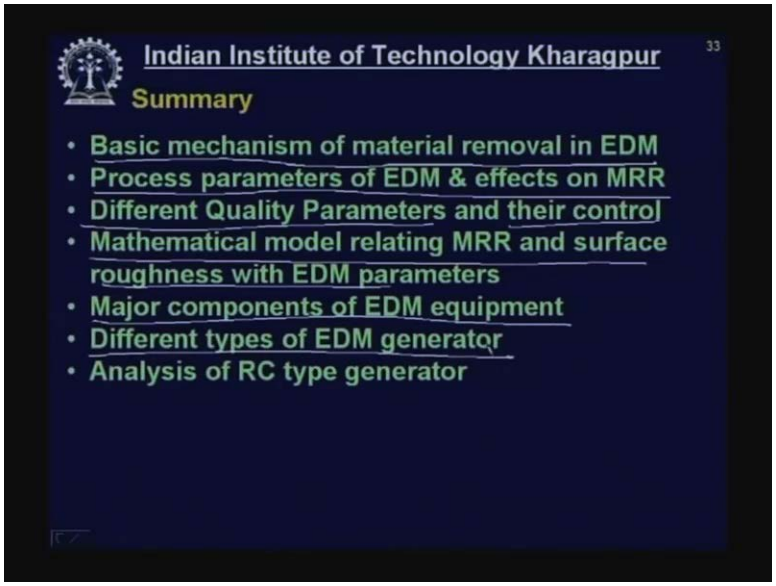

After going through this, we have discussed the basic mechanism of material removal in electro discharge machining. We have also identified the process parameters of EDM not only that, we have also studied there effect on material removal rate. We have developed a model relating material removal rate with process parameters. We have identified what are the different quality parameters and how they are related to process parameters and from that particular relation, we can control quality. One of our major achievement I would say is that, how do I reduce the surface roughness without sacrificing material removal rate? From those tools simple models, which we have developed we can say that without sacrificing material removal rate surface roughness can be reduce, how by reducing t-on but simultaneously reducing t-off as well. Mathematical models for MRR and surface roughness we have studied, we have identified the major components of electro discharge machining and we have also studied different types of electro discharge EDM generators and one of such generator is RC type generator which we have also done mathematical analysis. Now, let us come to the quiz questions:

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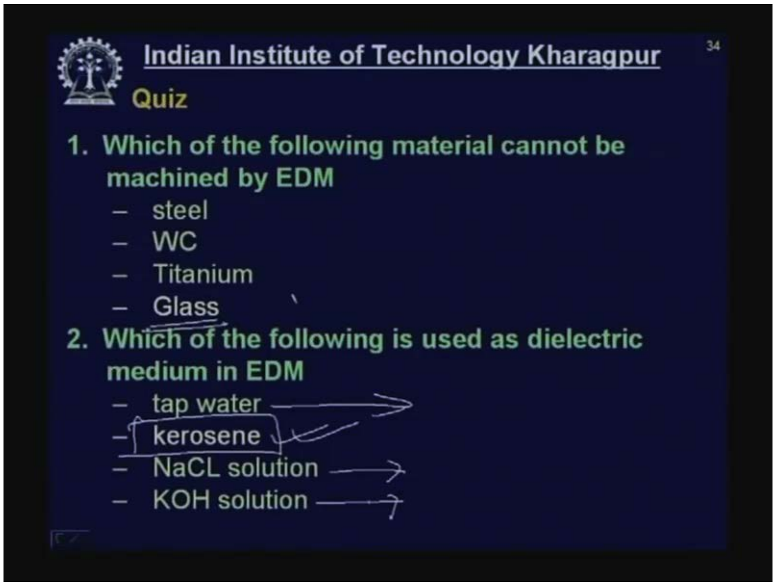

There are four quiz questions which are very simple, but they test your knowledge and understanding not only the knowledge, they also test your understanding. First one is which of the following material cannot be machined in EDM. You need not have to remember. We you know that, then to work material has to be electrically conductive steel is it electrically conductive. Yes, tungsten carbide is electrically conductive. Yes, titanium yes, glass is not an electrical conductor. Thus the answer is glass it cannot be machine by EDM. Next question: Which of the following is used as a dielectric medium in EDM? The first option is tap water. Tap water would be having salt in it.

So it cannot be used. Its ionization potential will be very less, sodium chloride as well as potassium hydroxide solutions they are basically this is a salt and this is an alkaline. So, they will ionize though solution will ionize instantly. Kerosene however would not because this is does not have any salt in it, it will not ionized. So the answer is kerosene. So it is not the question of memorizing things you can logically arrive at the answer by analysis.

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EDM tool should not have. What? It should not have high machinability. No, it should rather have machinability melting point. So what is the answer? Low thermal conductivity. It should not have low thermal conductivity, EDM tool material should be electrically conductive. It should not be electrically insulator. It should not be very hard. It should not be thermal insulator. It should be highly electrically conductive. After this, there are some problems. I am not going into those problems, you can see them off line. So once again to summarize we have studied the basic mechanism of electro discharge machining. We have identified the process parameters and we have developed mathematical models relating MRR and surface roughness with parameters. So with that, I hope it will help you in understanding electro discharge machining in a better way.

Thank you.