Advanced Machining Processes
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Module - 05
Lecture - 12
Electric discharge machining (EDM)

Welcome to the course on advanced machining processes. Today we are going to discuss a new topic that is called electrodischarge machining or in brief it is called EDM. So this machining process is very popular in the industry so many industrial modules industrial equipments are available and it is used in industry as like conventional machining process itself. As the name suggest this process it is a thermoelectric process.

So here electrical energy we are applying. So this electrical energy in its direct form is used for removal of material. So as the name suggest these process it can be used for electrical conducting material. So this material should have a limit, a small at least a small amount of electrical conductivity is required in the material so then only machining is possible but any kind of hard material can be machined by this process. So irrespective of its hardness this process can be used. So very smoothly it can machine but only limitation is that this material should be electrically conductive.

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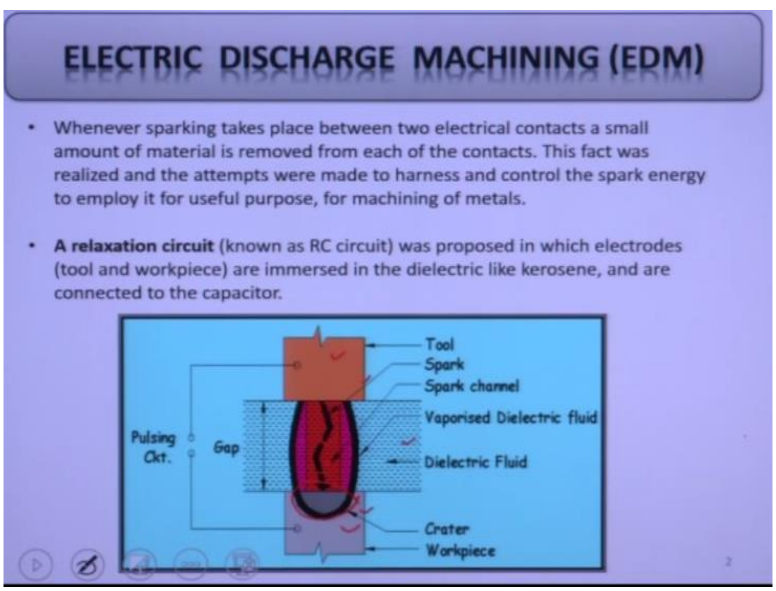

So we know this when some sparking occurs between 2 switches between the switches when sparking occurs in switches then small amount of material is removed. The concept actually it is used in a controlled manner in electric discharge machining process so whenever sparking takes place between 2 electrical contacts, a small amount of material is removed from each of these contacts. This fact was realized and the attempts were made to harness and control the spark energy to employ it for useful purpose for machining of metals.

So this concept actually already known to us. So some short circuit happens in between the switches and sparks occurs. Because of spark actually small amount of material is removed on the switches and that metal actually melts there. So this concept, same concept actually it is used for machining of metal okay so in EDM process same concept actually it is used. So in EDM process a relaxation circuit is used, RC circuit, it is commonly known as RC circuit.

So here this electrodes are actually tool and workpiece. So tool is actually here cathode and workpiece acts as an anode and these 2 things are actually it immerse, this tool and workpiece both the electrodes, cathode and anode are immersed into the dielectric fluid. This dielectric liquid it has a certain dielectric constant. So it is electrically neutral liquid. This dielectric liquid is electric neutral liquid, it has certain dielectric breakdown voltage.

When your applied voltage, applied potential is greater than this breakdown voltage then only this flow of current is there through this dielectric otherwise current does not passes through this dielectric. So here you can see in this figure. So this is the tool here and this is the workpiece which has to be machined by this EDM process. So you can see there is a spark occurs in between this tool that cathode and this workpiece.

This cathode or tool is connected to the negative terminal and this workpiece anode is connected to the positive terminal and you know this power supply it is connected through a RC circuit. In that RC circuit there is a capacitor is there. So when you are applying some DC voltage DC pulse power voltage so voltage is around 20 - 80 volt and with 5 kilowatt frequency, so when you are applying some DC pulse power voltage this capacitor charges and after that it discharges.

So this capacitor in that RC circuit it charges and this whatever this charge voltage is there it discharges through the dielectric in between this tool and workpiece. While it discharges this spark occurs at the minimum resistance. So minimum resistance is there where there is a interelectrode gap, IEG, interelectrode gap is minimum.

So you can see on the workpiece surface so under microscope you will see and tool also under microscope you will see there is a undulations are there. So this surface undulations are there in the tool as well as in the workpiece. So in that surface undulation where that minimum distance is there in between this tool and workpiece this sparking occurs with the minimum resistance, this sparks occurs with it follows through the minimum resistance between this tool and workpiece.

So it is the smallest gap between the tool and workpiece. So how this sparks occurs. When this capacitor charges so after charging it discharges and it applies a huge potential in between this cathode and anode. So this electrons from the cathode break loose from the cathode or from the tool it attracted towards the anode to the opposite charge of attracted towards the anode which is positively charged.

So there is a thousands of electrons which break loose from the cathode it directed towards the anode with a very high velocity. So depending on the potential you are applying through this RC circuit so depending on the capacitor discharge voltage so this velocity depends on how much potential you are applying in between these cathode and anode, in between this tool and workpiece.

So while coming to this traveling through this dielectric there, so this electrons actually it collides with the neutral molecule of the neutral atom of the dielectric fluid. So when it collides, this electrons comes outside from the neutral molecule, neutral atom of the dielectric, still more number of electrons actually coming outside. So so many electrons actually collide with the dielectric atoms and electrons this electrons actually comes outside from this atoms.

So there is a surge of flow of electrons from the cathode towards the anode and at the same time this ions which are positively charged. So it is this ions are actually directed towards the anode. So there is a ionization, there is a huge chunk of ionization is there, so electrons coming break loose from the cathode is coming towards the anode and ions it is directed towards the anode. So there is a hitting of electrode, hitting of electrode by these ions to the cathode and these electrons hitting of electrons with a very high velocity to the workpiece or anode.

So when your applied voltage from the applied voltage from this RC circuit is more than the breakdown voltage of your dielectric fluid then actually there is a spark occurs. So this spark is nothing but this flow of this ionization of electrons or hitting of electrons towards the anode and hitting of ions towards the cathode.

So these huge flow of electrons are there, huge flow of ions are there so when it hits then within a very small time, maybe thousands of second in a microsecond time so this sparking occurs. So because of this sparking occurs this molten material, this sparks occurs into a very small area into the microns, small micron, submicron area this sparking occurs though because of this sparking so material there on the workpiece surface melts and vaporizes and at the same time because of this hitting of ions also material from the tool also melts and vaporizes okay.

So there is a machining from the tool as well as from the workpiece surface. So because of this melting huge amount of heat is generated there. So because of this generation of this much of heat into a small area, we are considering only a only a single spark we are considering into a small area, huge amount of material is molten, it comes into the molten state or it comes into the vaporized state.

So this much material is removed from the workpiece surface because of this hitting operation. So it forms a crater from the workpiece. So this hemispherical craters are actually generated because of a single spark from a this crater height is it is very less maybe 1.2 to 1.5 micron and this depth this diameter of this crater is around maybe 10 micron okay.

So this much of small small craters are generated for a single spark. So when thousands of sparks are generated in 1 second because we are applying the power supply with 5000 hertz frequency so this 5000 sparks are generated in 1 second. So so many craters are generated on the workpiece surface just below the tool. So these craters are actually distributed over the workpiece surface where minimum distance minimum gap is there in between this tool and workpiece.

So this craters are distributed over all the workpiece surface, so just below the tool. So whatever the replica of the tool the same replica of the tool is generated into the workpiece surface itself. So this because of this EDM process you will get whatever tool depending on your tool, tool specification or tool shape, similar shape will be generated on the workpiece surface.

So any kind of complex shape can be generated, any kind of complicated shapes can be generated by this EDM process. So this tool and workpiece both everything is actually it is immersed into the dielectric fluid. So this machining actually is goes on into the inside the means total tool and workpiece everything is actually immersed into the dielectric fluid. So machining occurs inside the dielectric fluid only. So a relaxation circuit known as the RC circuit is proposed in which electrodes tool and workpiece are immersed into the dielectric. So this dielectrics are like kerosene and are connected to the capacitor.

So you can see here this is the dielectric fluid. So this tool and workpiece both are actually immersed into the dielectric fluid. So this is the spark here. So this is the spark channel. So total channel ionization channel is the total this spark channel is there, so the single spark. So this is the vaporized material. So this kind of craters, semispherical craters are generated. So vaporized dielectric fluid is coming outside. So here total ionization zone is there. So after this sparking occurs again this capacitor this means the capacitor discharges. Again this capacitor charges. So there is a on and off time. During off time there is no machining. So immediately around that zone where sparking occurs deionization occurs immediately.

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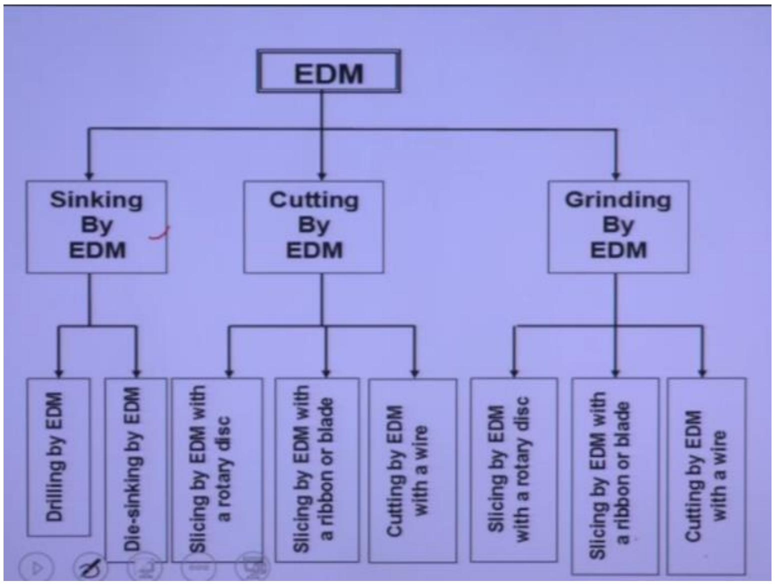

So using EDM process many things can be done. So there are different varieties of work can be carried out by this EDM process and these process actually we have to control in such a way that this tool wear rate should be as minimum as possible. So you have to control the parameters of this EDM process in such a way that this tool wear rate should be as minimum as possible okay. So we want more machining. So we are we are material removal is there from the tool as well as from the workpiece but we do not want any material removal rate from the tool.

So we want maximum material removal rate from the workpiece itself. So we have to reduce the tool wear rate so for reducing the tool wear rate you have to choose perfect tool material and you have to choose the optimum process parameter so that this tool wear rate can be minimized. So these are the different processes which can be done by this EDM process.

So sinking by EDM means total tool actually, tool which is the replica of the workpiece should be replica of the workpiece to be made on the workpiece surface. So this tool actually it is moving down towards the workpiece and same replica is generated from the workpiece surface. So it is called sinking by EDM. So it is called or it is called die-sinking EDM process.

So it is 2 types. It may be drilling by EDM process. You may drill circular holes, you can drill square holes, any kind of holes you can drill you can drill. So based on your shape of the tool, same holes will be generated into the workpiece surface. Another one is the die-sinking EDM okay. So this is the sinking by EDM process. Cutting by EDM, so you can cut the material also by EDM process. Slicing by EDM with rotary disc.

So you can you can use a rotating disc type metallic tool. So using this metallic tool you can do the cutting operation also on a very hard material. Suppose there is a very hard material is there you have to cut exact required portion okay so this kind of slicing by EDM operation you can do using a rotary disc type tool.

So slicing by EDM by a ribbon or blade, so you can buy a ribbon or blade, you can do the slicing operation. Cutting by EDM by a wire. So you can use a wire also. This wire you can use for cutting operation. That is called wire cut EDM. So this wire you can move. So while moving so you have to do the flow of dielectric in between this interelectrode gap and we will do the machining operation okay. So here this wire is used as a cathode.

So grinding by EDM operation okay. So slicing by EDM with a rotary disc grinding tool. Slicing by EDM using a ribbon or blade or cutting by with a wire. So grinding operation also we shall discuss this thing electro-discharge grinding, electro-discharge diamond grinding, different kinds of grinding operations are there. There we can take help of the EDM process as well as normal grinding operation to increase the performance of the process.

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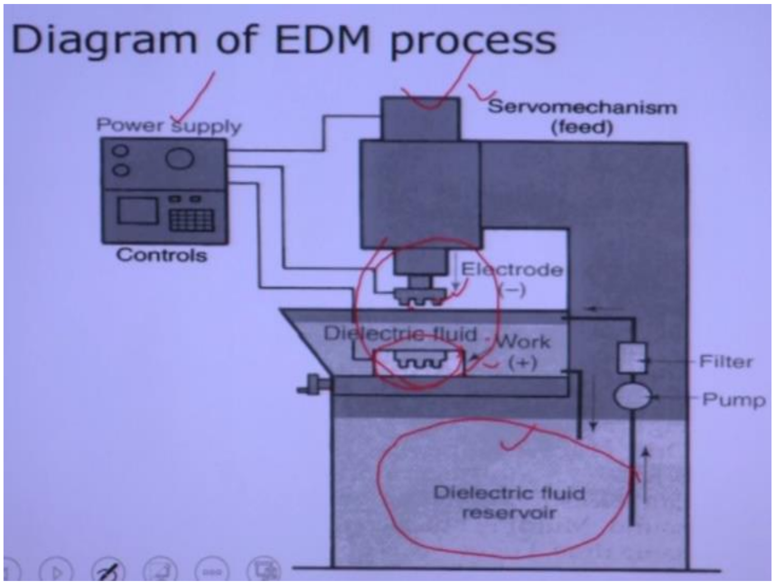

So this is the diagram of the tool diagram of the EDM process, different components of the EDM process. So this is the tool here. You can see this protrusion here in this tool. So similar protrusion will be generated into the workpiece surface. So this is the this is the electrode or cathode. It is called the cathode and this is the workpiece. You can see that similar protrusion is generated into the workpiece surface.

So here this is tool and workpiece both are actually immersed into the dielectric fluid. So this tool is actually connected to the negative terminal of the DC power supply, workpiece is connected to the positive terminal of the DC power supply. So this is the control unit of the power supply. There is a servomechanism is there. Now what is the use of the servomechanism? So if there is a minimum interelectrode gap is requires so unless you put this cathode and anode in between this interelectrode gap in between this range of this interelectrode gap there will not be any machining.

So for the machining to takes to start this there is a interelectrode gap which is in the which is in the micron range. So this distance between this tool and electrode that is called the tool and workpiece that is called the interelectrode gap. So we have to maintain this interelectrode gap into the submicron range. Then only this EDM machining will start. So while this machining is going on so material will be removed from the workpiece. So this interelectrode gap when this craters are forming this interelectrode gap will be increased.

So if this interelectrode gap increased then after some time you will see that there is no machining is going on. No material removal rate is going on because a certain gap is required, minimum gap is required for the material removal rate to start but when this gap is more than this critical interelectrode gap then there will not be any machining.

So you have to feed the tool towards the workpiece surface to maintain the gap, to maintain that interelectrode gap. So you have to feed the tool towards the workpiece surface. So for fitting the tool towards the workpiece surface you need a servomechanism, servomotor. Also there are different activities of the servomotors are there. So it actually it acts as a gap voltage sensor. So using this gap voltage it maintains the gap in between this tool and workpiece.

So there is a electrode chamber sorry dielectric chamber is there. So in that dielectric chamber from this machining zone this dielectric actually taken outside to the dielectric chamber there filters are there. It is this dielectric property is conditioned and monitored. So temperature, temperature is maintained. So whatever debris materials are there this debris materials particles are actually removed by this filtering system from this dielectric. So after removing this debris materials up to 2 micron size diameter of debris particles these dielectric again it is recirculated into the machining zone. So it is recirculated using a pump, using a centrifugal pump this dielectric fluid is actually recirculated in between the machining chamber.

So a centrifugal pump is used for doing that thing okay. So a EDM experimental setup consist of there is a EDM power supply, there is a tool and electrode, sorry tool and workpiece and then there is a servomechanism is there and fourth one is the dielectric fluid and its feeding system into the machining zone. So these are the 4 different components of the EDM electro-discharge machining process.

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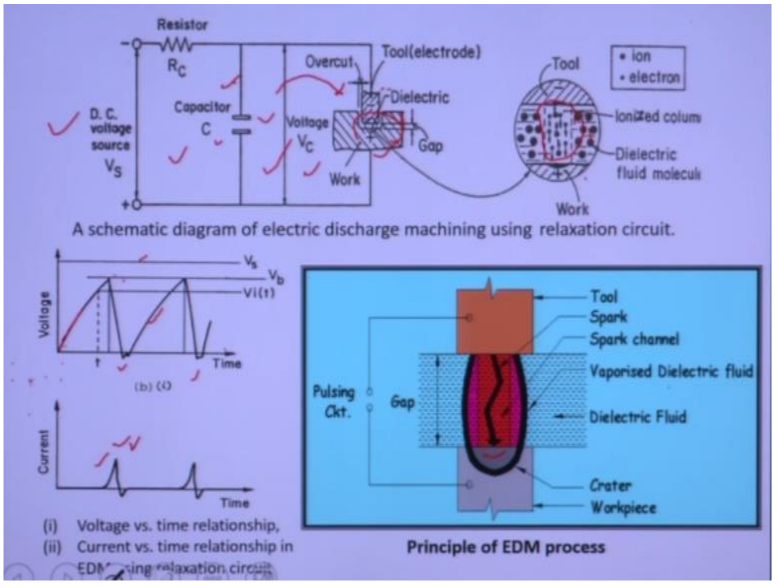

So you can see here this is the RC circuit resistance it is called resistance capacitor circuit or relaxation circuit is there. So here DC supply voltage is there. So this DC supply voltage you can say here this Vs is the DC power supply voltage. So this is the capacitor which is charged. While it is charged, after charging it discharges. So there are 2 circuits are there. This is the charging circuit, this is the discharging circuit.

So in this charging circuit you can see this charging resistance is R C and this is the capacitance of this capacitor is C and this is the discharging circuit. In the discharging circuit this discharging voltage is V C here and this is the tool here, this is the workpiece in between this dielectric interelectrode gap is there. So tool is as a electrode workpiece is here it is anode, it is connected to the negative and positive terminal, tool is connected to the negative terminal that is why it is called cathode and workpiece is connected to the positive terminal here. So this is the interelectrode gap here. So this exaggerated view of this interelectrode gap here you can see this electrons breaks loose from the tool which is coming towards the work and this ions, right hand side and left hand side we can see these are the ions are there. This ions actually it is attracted towards the cathode.

So this is the ionized column, so this is the ionized total ionized column okay. So when this ionized column actually flown towards the towards the anode okay so then huge amount of energy actually released in the form of a spark okay and this kind of craters is generated. Now coming to this voltage this capacitor you can see this one is the voltage and current diagram of the capacitor. So here this voltage diagram with respect to time for capacitor C here.

So you can see so this voltage in the capacitor charges or this capacitor charges from 0 volt to a certain voltage, breakdown voltage, and this is the supply voltage V S. So this capacitor is charged form voltage 0 to a breakdown voltage V b. So this capacitor charges. It is a function of time. With time actually it charges.

When it is reaches to the breakdown voltage then spark occurs. So when it is reaches to this breakdown voltage at that time there is a spark occurs. When spark occurs you can see there is a momentary current impulse. So there is a current flow through this interelectrode gap when this capacitor is applied voltage to this capacitor is more than the breakdown voltage okay. So when capacitor discharges and then current flows through this interelectrode gap here again capacitor discharges here, again this capacitor charges and again discharges charges like that this slope this loop actually continues okay.

So there are thousands of spark in 1 second is there. So thousands of craters are generated in 1 second. So although this diameter of this craters are very small but there are frequency of this current we are using is 5000 K, so 5 kHz okay 5000 Hz so so many sparks are actually generated in 1 second okay. So so many craters are actually formed.

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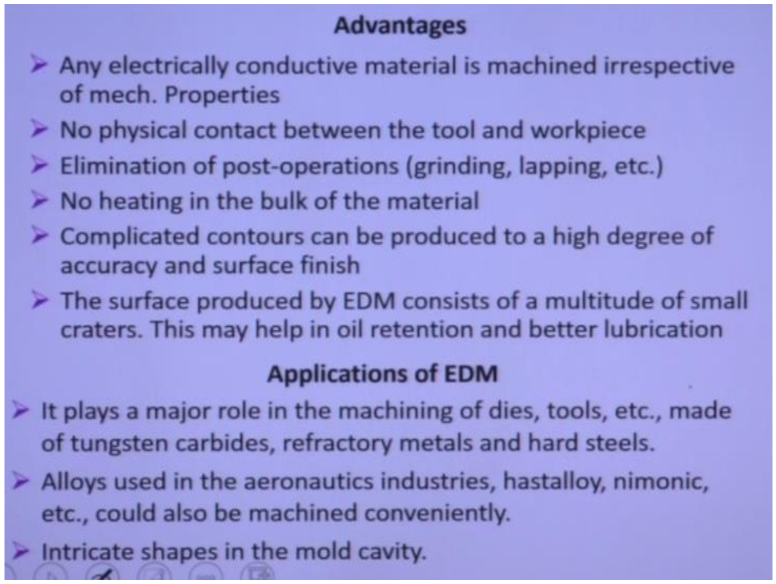

So this advantages is there. Any electrically conductive material is machined irrespective of its mechanical properties, mechanical properties means irrespective of its hardness or any other properties okay. So any kind of conductive material can be machined, any hard conductive material irrespective of its hardness it can be machined. There is no physical contact between the tool and workpiece.

So like in conventional milling or conventional turning operation there is a physical contact between the tool and workpiece. So by this process you can machine any thin section materials also because there is no there is no contact in between this tool and workpiece. So any thin section, delicate components also can be machined by this process.

Elimination of post-operations like grinding, lapping. So like in conventional machining operation, after machining you have to do the finishing operation also. So in EDM process you do not need to do this post machining operation so this lapping, honing, this kind of finishing operation you do not need to do after machining.

So no heating in the bulk of the material. So only where this sparks where this spark actually generates sparks actually occurs, in that case only actually this crater which is in the submicron range there only heated this material is heated so entire bulk material is not heated like in conventional machining process.

So complicated contour can be produced to a high degree of accuracy and surface finish. Any kind of complex contours can be produced by this process because you have to make the tool in such a way that this tool is the prototype of the workpiece to be, workpiece shape to be machined okay. So you can make the prototype of the tool, so you can generate the same prototype into the workpiece surface. So this surface produced by EDM consist of a multitude of small craters. This may help in oil retention because so whatever surface is generated it is a combination of this craters. Somewhere this craters actually overlaps there. So this kind of matte finish actually generated. So because of this EDM surface this craters are visible there, craters are available so it helps in oil retention and better lubrication process.

So applications of EDM, so it plays a major role in the machining of dies and tools, dies and tools industries which are made of tungsten carbide, refractory metals, and hard steels, hardened steels are used. So this dies and tool industries actually they are extensively use this EDM process. So alloy used in the aeronautics industries, hastalloy, nimonic could also be machined conventionally conveniently by EDM process. Intricate shapes in the mold cavity can be generated by this EDM process.

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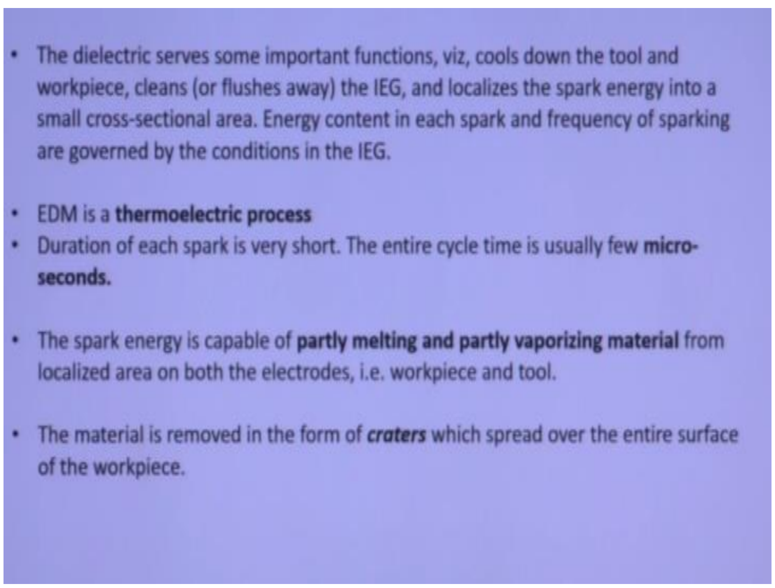

So this dielectric in between this tool and electrode, in between this interelectrode gap it acts actually some functions. It cools down the tool and workpiece so because of heating of this part huge amount of heat is generated on the when the spark occurs although it is in the submicron range but this metal actually melts as well as evaporates evaporate there. So this dielectric actually it removes the heat, whatever heat is generated from the tool and workpiece and it also this dielectric actually it is flown in between this interelectrode gap. There are different flowing systems are there, we shall discuss later. So because of this flowing of this dielectric it flushes away whatever this debris particles are there it flushes away or cleans away.

Also this dielectric localizes the spark energy into a small cross-sectional area. So because of this using this dielectric whatever the sparking is occur it localizes into a small cross-sectional area so means this energy can be localized into a small area okay. So energy content in each spark and frequency of sparking are governed by the conditions of the interelectrode gap.

So EDM is a thermoelectric process. We are using a electrical energy to thermally heat and then melt and vaporize the material into the interelectrode gap from a crater. So duration of each spark is very short. The entire cycle time is usually few microsecond. So this total cycle is very short and within few microseconds actually this charging, discharging, deionization all these things actually happens. So this spark energy is capable of partly melting and partly vaporizing the material from the localized area from both the electrodes that is from both workpiece and tool.

So this material is removed in the form of craters which spread over entire surface of the workpiece. So this craters actually it spreads on the entire surface of the workpiece. So particle (()) (31:45) from the electrodes are known as the debris. So whatever this material actually molten state and then what is whatever vaporizes these are actually molten material. It comes outside inside the dielectric fluid so these are called the debris.

So it is a mixture of irregular shaped particles, this irregular shaped particles is because of this from molten metal, metal from the molten state it metal from the molten state it comes into the dielectric okay so it takes the shape of the irregular shape of the debris and whenever this metal if it evaporates and it is cools down, after cooling down it will it takes the spherical shape.

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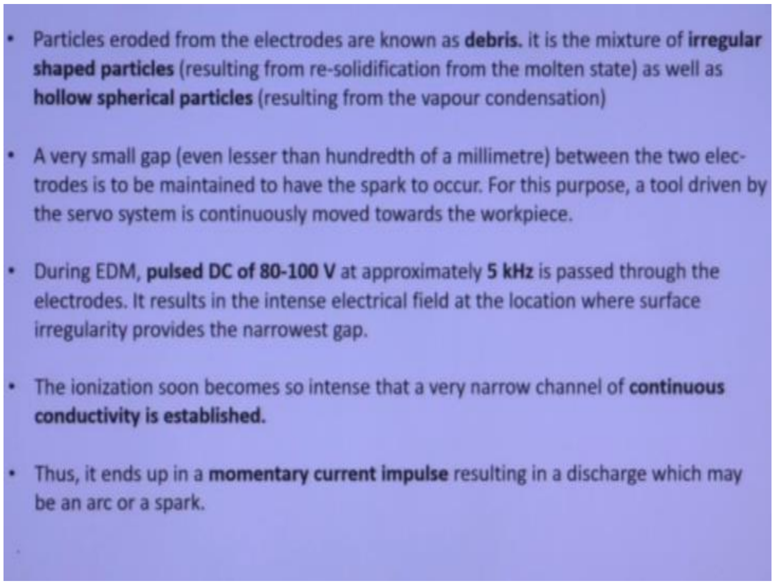

So this is the irregular shaped particles resulting from the re-solidification from the molten state as well as hollow spherical particles. This hollow spherical particles are resulting from the vapour condensation. A very small gal that is lesser than hundredth of a millimeter between the 2 electrodes is to be maintained to have a spark to occur. For this purpose a tool driven by the servo system is continuously moved.

This tool is fed towards the workpiece by the servo system okay it is fit towards the workpiece by the servo system. During EDM operation pulsed DC 80-100 V at approximately 5 kHz is passed through the electrodes. It results in the intense electrical field at location where the surface irregularity provides the minimum or narrowest gap. So there resistance will be less, smaller resistance where the narrowest gap is there and there craters occur. So this ionization soon becomes so intense that a very narrow channel of continuous conductivity is established. This ends up in a momentary current impulse resulting in the discharge which may be an arc or a spark.

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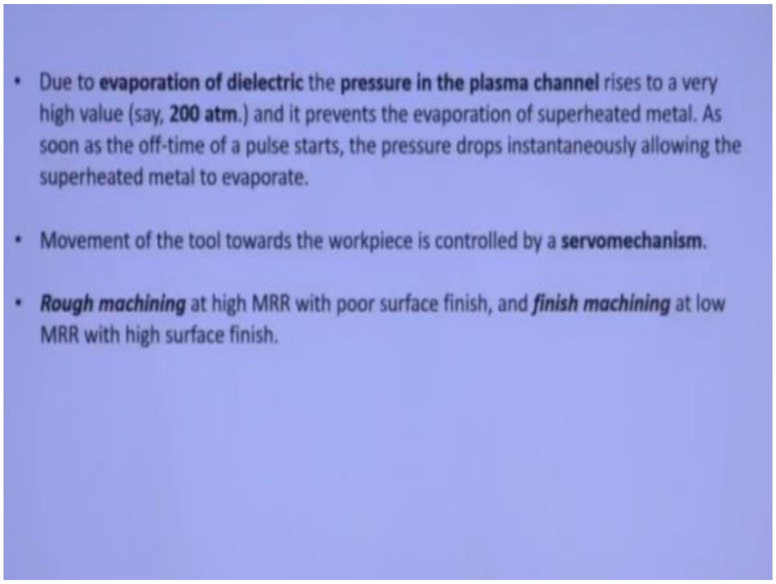

This evaporation of dielectric due to the evaporation of the dielectric the pressure in the plasma channel rises to a very high value 200 atmospheric pressure and it prevents the evaporation of the molten material, in the superheated molten material. So as soon as the off-time of the pulse starts, the pressure drops instantaneously and along the superheated metal to evaporate. So movement of this tool towards the workpiece surface is controlled by the servomechanism. So rough machining at high material removal rate and poor machining, poor surface finish which gives the poor surface finish and finish machining at low material removal rate with high surface finish.

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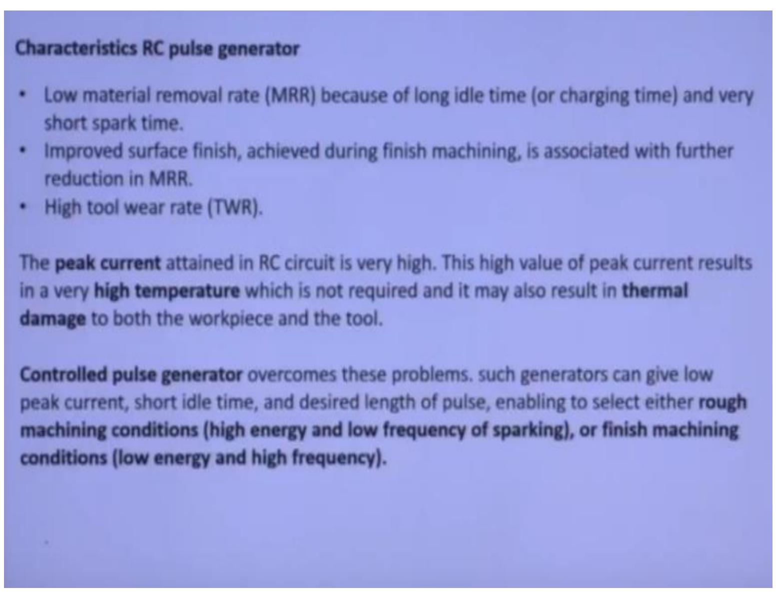

So what are the characteristics of RC pulse generator. So using this RC pulse generator this material removal rate is very less because of long idle time. Idle time is that charging time. So this capacitor takes a longer time for charging so it has a longer idle time so that is why this material removal rate is very less in case of when you are you are using the RC pulse generator.

So improved surface finish achieved during finish machining is associated to the further reduction in material removal rate. So also in RC pulse generator another disadvantage is that it has a high tool wear rate. So this peak current obtained during this RC pulse circuit actually it is very high. This high value of peak current results in the high temperature which is not required and it may result in the thermal damage to both the workpiece and the tool.

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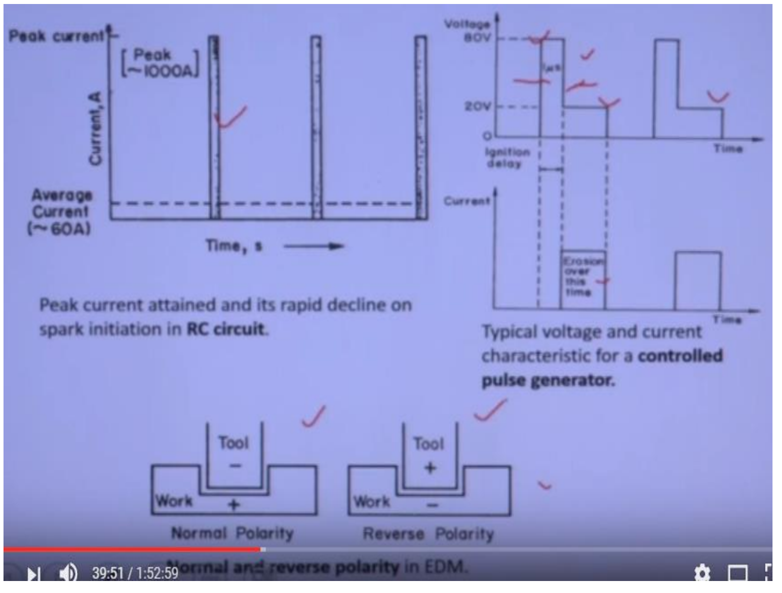

So this peak current obtained, so you can if you see this, this is the peak current obtained during this RC circuit, it is very high okay. So it is very high. So that much of peak current is not required for melting and vaporization okay. So this peak current obtained in RC circuit is very high. This high value of peak current results in a very high temperature which is not required so because of this high peak current it results in high temperature which is not required and it may be also result in the thermal damage.

It may results in the thermal damage to both the workpiece and tool. So because huge peak current is generated around 1000A so that much of peak current actually not required. So because of this high peak current huge amount of heat is generated in case of RC circuit. So as the huge amount of heat is generated it results in a thermal damage to the workpiece and the tool.

So this kind of things actually this kind of disadvantages can be removed from the controlled pulse generator which overcomes this problem.

Such generator can give low peak current, short idle time, and desired length of the pulse. So these kind of problem of this RC circuit can be removed by the controlled pulse generator. So it can give low peak current, short idle time, and desired length of the pulse enabling to select the either rough machining of high energy and low frequency of sparking or finish machining conditions where low energy high frequency of current is there.

So that is the that is available in controlled pulse generator. So you can see here in controlled pulse generator so 0 - 80 V so here this circuit actually it or capacitor charges at this point so after charging actually it takes some time for discharging. So for the capacitor after charging it take some time for the discharging. This time actually it is called ignition delay time. So this ignition delay actually it is very less in case of controlled pulse generator.

So this ignition delay you can control. By controlling this ignition delay this amount so time over which your material removal occurs okay, the sparking occurs actually can be controlled. So erosion occurs during this over this time okay. So this typical voltage and current characteristic for controlled pulse generator. There are 2 types of mode modes are there. One is called normal polarity another one is called the reverse polarity.

In normal polarity cathode, tool is actually cathode, anode is workpiece. In normal polarity this tool it is connected to the negative junction of this DC power supply and tool is actually connected to the positive junction of the DC power supply. So this is the normal polarity here. But in reverse polarity actually tool is positive and workpiece is negative. So this is the normal polarity, this is the reverse polarity. So in reverse polarity this is just opposite to normal polarity. In reverse polarity tool is positive and workpiece is negative.

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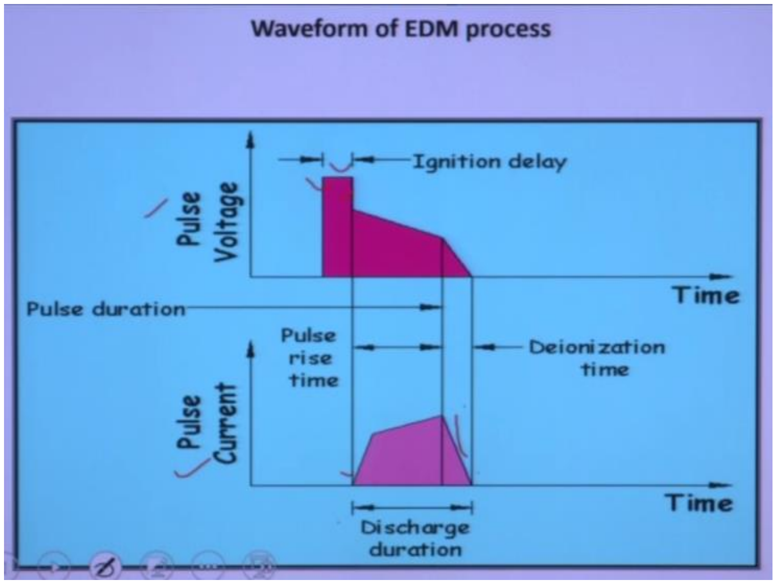

So this is the controlled pulse generator. Here you can see this ignition delay. Delay is the after this breakdown voltage is achieved how much time is required by the capacitor for the discharging to takes place, for the discharging how much time, before discharging how much time is required. So this is the before means after charging how much time is required for discharging. So this is called the ignition delay time.

So this is the voltage and this is the pulse current over time. So here it is it is releasing this capacitor, here it is actually breakdown voltage is achieved. So there is a ignition delay time to discharge the capacitor. After that you can see here this sparking starts from here. So it reaches to a maximum value and after that it goes down.

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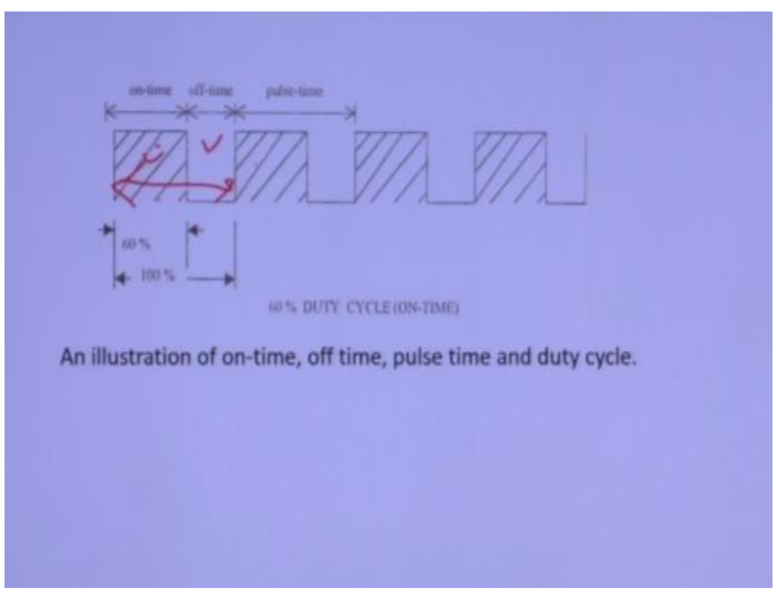

So this is the square pulse you can see here. So this is the on-time and this is the off-time of the square pulse and this is the total time, total cycle time. So this is the first one, on-time, off-time and this is the total cycle time. So from here you can calculate what is the duty cycle. So duty cycle is nothing but on-time by total pulse time will give the duty cycle. So this is in case of your square wave, square DC pulse power supply.

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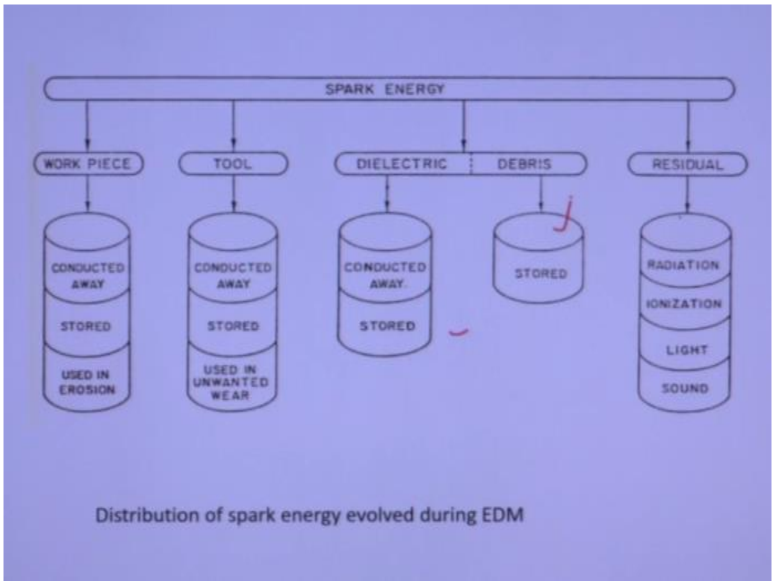

So whatever this heat is actually generated because of this spark how this heat is actually distributed. So some amount of heat is actually gone towards the workpiece, it is conducted away, it may be stored there inside that capacitor and it may be used as the used in erosion process. Now tool, tool also ion bombardment is there into the tool so some amount of heat is actually conducted away, some amount of heat is actually stored inside the tool and some amount of heat actually it is used in unwanted wear.

So dielectric, so this whatever heat is generated it may be taken away by this dielectric fluid so it is it may be conducted away into the dielectric fluid or it may be stored in the dielectric fluid chamber. So this debris also during machining actually this debris also there in between this tool and electric so this debris also some amount of heat maybe translated into this heat into the debris and other heat like radiation, ionization, light, sound, so these kind of things are actually going on simultaneously.

So other things actually other heat is termed as the residual heat so it is so this heat losses also are there. So whatever this spark energy is there it is conducted away into the tool so it may be stored in that tool and it also may be used in unwanted wear in the tool and spark energy, some portion of the spark energy it is conducted away into the workpiece. It is stored into the workpiece and it is used in erosion process. So it may be, so spark energy it may be conducted away, conducted away into the dielectric.

It may be stored into the dielectric and it may be conducted away into the debris or stored into the debris and residual of the spark energy it may be radiated, it may be ionization in light and sounds actually it is wasted. So this is the distribution of this spark energy to the tool workpiece debris dielectric and other residuals are there.

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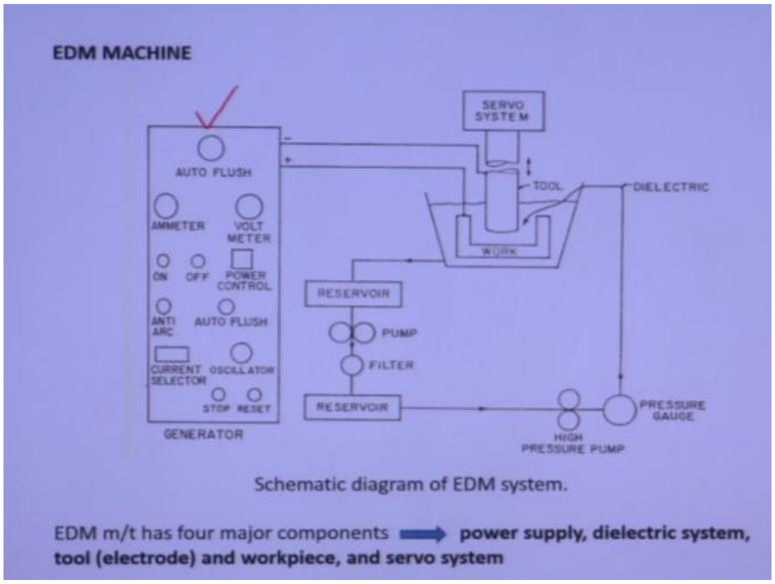

So you can see this is the EDM schematic diagram of the EDM experimental setup. So there are 4 components are there. One is the power supply, this is the one component of this EDM process. Second one is the dielectric system. So dielectric fluid system is the second part. So it consist of this pump, delivery system, filtering system, dielectric fluid, dielectric fluid tank. Then third one is the servo system which gives speed to the tool and fourth one is the tool and workpiece. So these are the 4 major components of the EDM machine tool.

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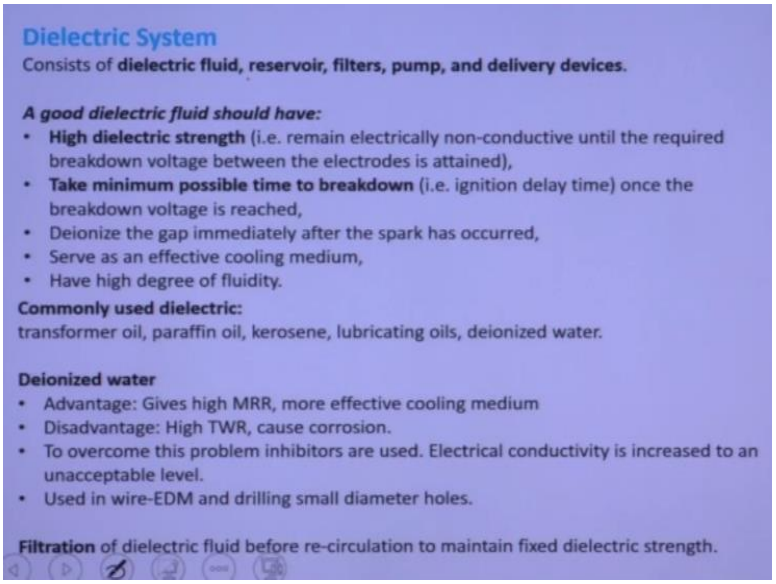

So dielectric system, so in dielectric system, first one is the dielectric system so consist of dielectric fluid, reservoir, filters, pump, and delivery devices. So a good dielectric fluid has the following properties. It should have high dielectric strength. So it should not break down easily. So it should have high dielectric strength, so it should remain electrically nonconductive with a very high voltage, high potential applied. So until its breakdown voltage between means it remains electrically nonconductive until the required breakdown voltage between the electrodes is attained.

Take minimum possible time to breakdown. So this breakdown, so it is called actually ignition delay time. Ignition delay is the time required after its breakdown voltage is achieved. This time required for this breakdown of this capacitor is called the ignition delay. So this good dielectric should have a very less ignition delay time once the breakdown voltage is reached. So after this sparking occurs the zone actually ionizes and during off-time it should be deionized.

So this deionization time should be as less as possible. So deionize the gap immediately after the spark has occurred and this dielectric shoot act as a effective cooling medium okay. So it should take away whatever unnecessary heats are there it should take away and it should have a high degree of fluidity. Suppose you want to make a very high length to diameter ratio, high aspect ratio holes there in between this means tool and workpiece you have to flow the dielectric there to continue the machining.

So for flowing this dielectric there so this dielectric fluid has should have actually very good fluidity, its viscosity should be low so that it can be flown in between this small gap when you are making high aspect ratio holes. So commonly used dielectric fluids are transformer oil, paraffin oil, kerosene, lubricating oil, or deionized water. Deionized water actually it is it has certain advantage, gives high material removal rate. So it acts as a more effective cooling medium but it has a certain limitations. It has a high tool wear rate. So because of this high tool wear rate you cannot use this dielectric deionized water everywhere.

So it has a corrosion property. So this because you are using deionized water so if something if you are using steel mild steel so it corrodes. So to overcome this problem inhibitors are used to reduce the corrosion problem inhibitors are used, but if you use this inhibitor this dielectric constant of this deionized water actually reduces.

So electrical conductivity increased and this dielectric constant actually reduces to an unacceptable level. So that is why you cannot use inhibitor to a quantity of inhibitor to a certain limit, beyond a certain limit. So this deionized water, it is mostly used in wire-EDM process and small where this small high aspect ratio small diameter holes are actually made so there also this deionized water is used.

Filtration of this dielectric before re-circulation to maintain the fixed dielectric strength. So if this debris particles are actually it is in the micron size so if it is mixed into this dielectric so its dielectric constant actually increases sorry its dielectric constant decreases okay. So it breaks down with a lower voltage. With lower voltage also it breaks down. So to keep a dielectric, dielectric fluid same dielectric constant okay to maintain its same dielectric constant this dielectric has to be filtered and it should be re-circulated into the machining zone. So there are different ways you can apply this dielectric fluid into the interelectrode gap. So first one is the suction through the workpiece, suction through the electrode.

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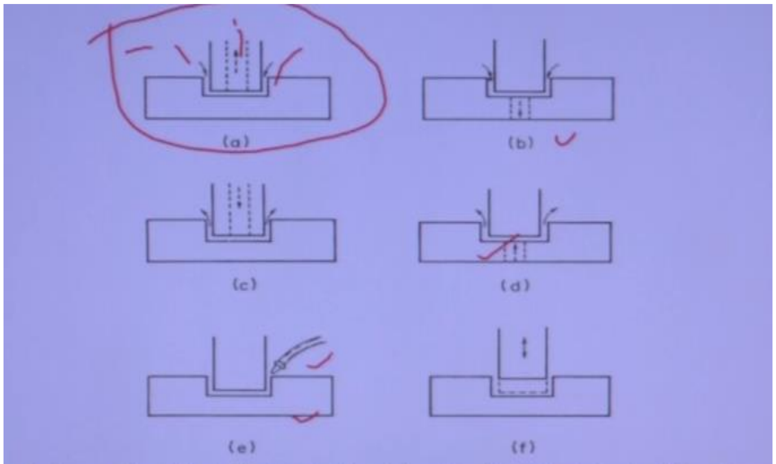

Various methods for **dielectric flushing**: (a) suction through electrode, (b) suction through workpiece, (c) pressure through electrode, (d) pressure through workpiece, (e) jet flushing, (f) periodic cycle of electrode [HMT, Bangalore, Catalogue].

So here this tool is there. Inside the tool there is a hollow, this is the hollow they have used a hollow tube. So this dielectric fluid actually it is sucked and so it total thing actually it is immersed into a dielectric chamber okay. So this from this tool there is a hollow tool, this dielectric is sucked there and from this outside you can see this dielectric is coming into the interelectrode gap. Second one is that this dielectric can be sucked through the workpiece also.

This is the second option. Now third option is that this is a very good option, mostly it is used, dielectric can be delivered through the hollow tube through the through the tube, through the tool dielectric can be delivered into the interelectrode gap and it is coming outside from this interelectrode gap. So here through this workpiece also you can flow this dielectric in d. So through this workpiece also you can flow this you can deliver this dielectric and it is coming outside from the interelectrode gap.

In e here in this figure you can see dielectric can be delivered through this jet flushing. So using this jet flushing technology, through a nozzle you can deliver this dielectric into the interelectrode gap. Otherwise you can do this flow of electrolyte you can so you can flow this dielectric by periodic cycle of the electrode. So this you can vibrate this tool with a ultrasonic vibration. So this tool is vibrated with a ultrasonic vibration. If it vibrates with a ultrasonic vibration okay. So what about this debris particles are there because of this vibration of this tool it actually comes outside. So this ultrasonic vibration this concept actually it is used in micromachining operation or in micro-EDM operation.

So EDM operation, micromachining operation using EDM okay. In micro-EDM operation this vibrating tool with a ultrasonic frequency it is used to remove the dielectric fluid to remove the debris from the interelectrode gap. So this debris should be removed from the flushed away from the interelectrode gap. If this debris actually it is there is a concentration of debris there inside the interelectrode gap then what will happen dielectric constant or breakdown voltage of this dielectric actually reduces and it with a lower voltage also this machining occurs there.

So you will not get the required material removal rate with the lower value of breakdown voltage. Also there is a chances that this bigger size debris particles maybe choked in between this interelectrode gap and there may be short circuit. So there may be short circuit may be there in the interelectrode gap. So that is why so you have to remove the debris from the interelectrode gap by this kind of process, by flowing this dielectric fluid in the interelectrode gap.

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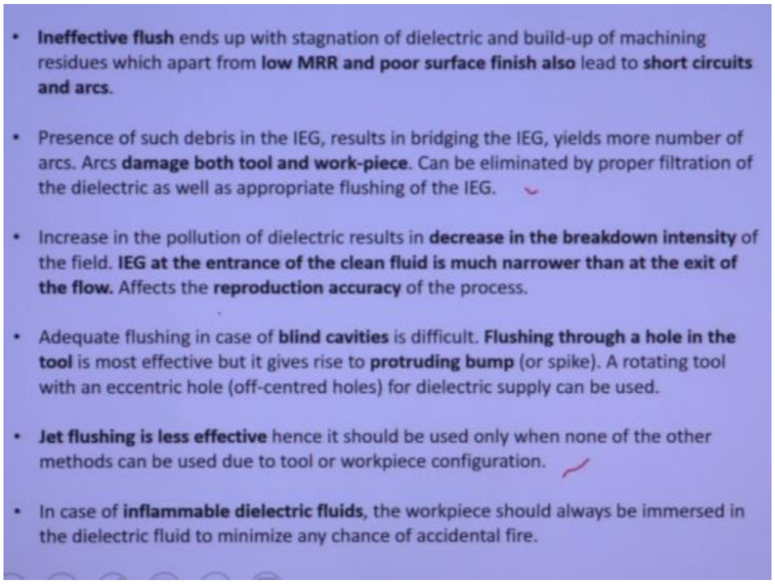

So ineffective flush end up with the stagnation of dielectric build-up of machining residues which apart from lower material removal rate it will generate poor surface finish and lead to the short circuit and arcs. Presence of such debris in the interelectrode gap results in the bridging of the interelectrode gap, yields more number of arcs. So this arcs actually damage both the tool and workpiece. Can be eliminated by proper filtration of the dielectric as well as appropriate flushing of the interelectrode gap.

Increase in the pollution of dielectric results in the decrease in the breakdown intensity of this filed, in the field. Interelectrode gap at the entrance of the clean fluid is much narrower than at the exit of the flow. So at the entry we will see this it is cleaner dielectric fluid is coming at the interelectrode gap. At the entry cleaner dielectric fluid is coming. So here a nano gap will be maintained, but at the exit because of this more concentration of this debris particles at the exit there after machining so you will see that this gap will be more there interelectrode gap will be more at the exit than at the inlet of the interelectrode gap. So it affects the reproduction accuracy of the process. So adequate flushing in case of blind cavities is difficult.

Suppose you are making a blind cavities, so you cannot flow the dielectric through the workpiece or either to the tool okay. So in case of blind cavities this adequate flushing is difficult. Flushing through a hole in the tool is most effective, but it gives rise to protruding bump. So through the tool also you can flow the dielectric whatever it is shown here.

Through this through this tool also you can flow the dielectric, but where you are flowing this dielectric there, there is no metal is there to spark to occur so there will be protruding bump maybe observed. So similar kind of protrusion of this material will be there, similar kind of things are actually observed in case of ECM process also but this one can be actually removed by rotating this tool and making this hole inside the tool, off centric hole inside the tool and rotating this tool so by rotating this tool so whatever this protruding bump is there so can be removed.

So another options of actually flowing giving this flushing of this dielectric in the interelectrode gap by rotating the tool, by rotating you can generate a turbulence there and you can remove the debris from the interelectrode gap. Jet flushing is less effective, hence it should be used only when none of the other methods can be used due to the tool and workpiece configurations.

So this is the jet flushing here. So it is the ineffective process. So it can be used when none of the other process other systems works, other systems for providing dielectric in the interelectrode gap works then only this jet flushing through a nozzle can be used. In case of inflammable dielectric fluid you have to keep the tool and workpiece immersed into the immersed into the dielectric fluid so that any kind of accident to reduce any kind of accident. So electrodes the 2 electrodes in EDM process is the means of providing electrical energy to the work material.

Machining accuracy depends on the form stability of the tool under the severe electrical and flushing stress conditions. It should have wear resistance. The ability of an electrode to produce and maintain the detail, maintain detail is directly related to its resistance to wear and machinability. Minimizing corner wear requires choosing an electrode material that combines higher strength with a high melting point.

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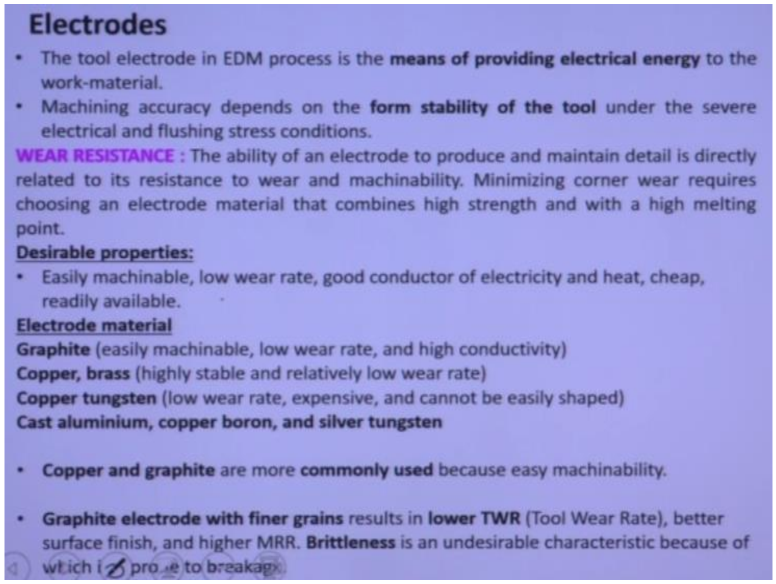

So what about the desirable properties of that electrode material? So it should be easily machinable. It should be a soft material, soft material can be easily machined. So it should have low wear rate, good conductor of electricity and heat. It should be cheap and it should be readily available. So these are the different desirable properties of tool material. So different electrodes are actually used like graphite, copper, brass, copper tungsten, cast aluminium, copper boron, and silver tungsten.

Graphite it is easily machinable. It has a low wear rate, high conductivity, but what is the main problem of this graphite although it has a low tool wear rate but at high surface finish and high material removal rate but brittleness is an undesirable property characteristics because of which it is it is prone to breakage. So it is a very brittle material. So with a very small force also it breaks. So that is the main problem of using graphite although it is a very good it has a very good property of being a means EDM tool. It is easily machinable, high material removal rate, and also low tool wear rate is also there.

Copper, brass, it has a high, highly stable and relatively low wear rate is there. Copper tungsten low wear rate although it is expensive but cannot be easily shaped. Other things are there cast aluminium, copper boron, and silver tungsten. So copper and graphite based on this all whatever tool materials are there, copper and graphite are mostly commonly used because of their easy machinability. Graphite electrode with finer grains results in low tool wear rate, better surface finish, and higher material removal rate.

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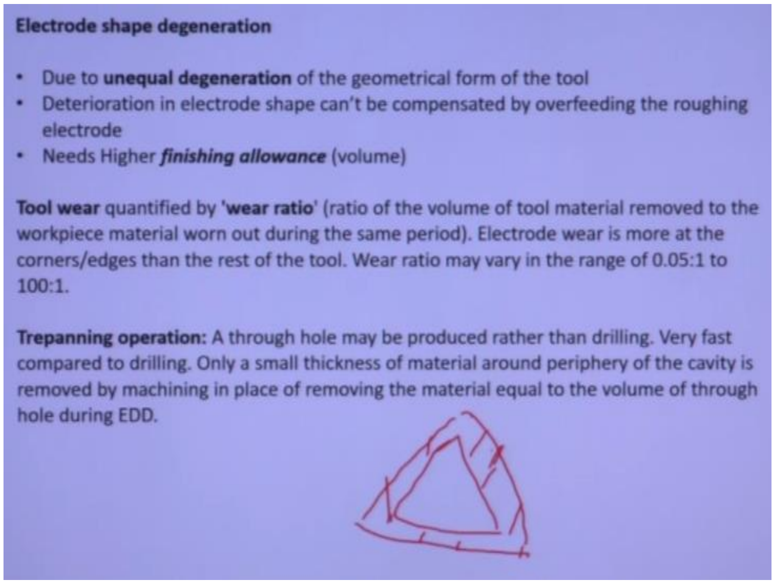

Electrode shape degeneration, so due to the unequal degeneration so because suppose you have taken a cylindrical tool so that corner of the tool actually your electric field intensity will be more, so this corner portion will be there will be radial means radial radius formation will be there. So this degeneration will be there at the corner points. So wear out will be more at the corner points of this cylindrical tool. So due to the unequal degeneration of the geometrical form of the tool electrode shape degenerates.

Deterioration of electrode shape cannot be compensated by overfeeding the roughing tool. Suppose this tool wear is there so that portion whatever this tool wear is there cannot be compensated by overfeeding the roughing tool, roughing electrode. So we need a very high finishing allowance. So tool wear quantified by the wear ratio, so it is the ratio of the volume of the tool material removed by volume of the workpiece material removed during the same period. So electrode wear, electrode wear is more at the corners or edges of this means electrode or cathode than the rest of the tool.

So wear ratio may vary in the range of 0.05:1 to 100:1. Another operation is the trepanning operation. So in drilling operation entire volume of material is removed. Suppose this kind of material is removed has to be removed, so we can use this kind of tool here and instead of using total volume of tool is there so we can use a this kind of tool we can use okay so this kind of tool can be used. So this portion of material will be removed from the workpiece okay. So now this total volume of material can be removed okay. So this is called the trepanning operation.

A through hole may be produced by rather than drilling. Very fast this is very fast compared to drilling operation. Only small thickness of the material around the periphery of the cavity is removed by machining in place of removing the material equal to the volume of the through hole during electro-discharge drilling operation.

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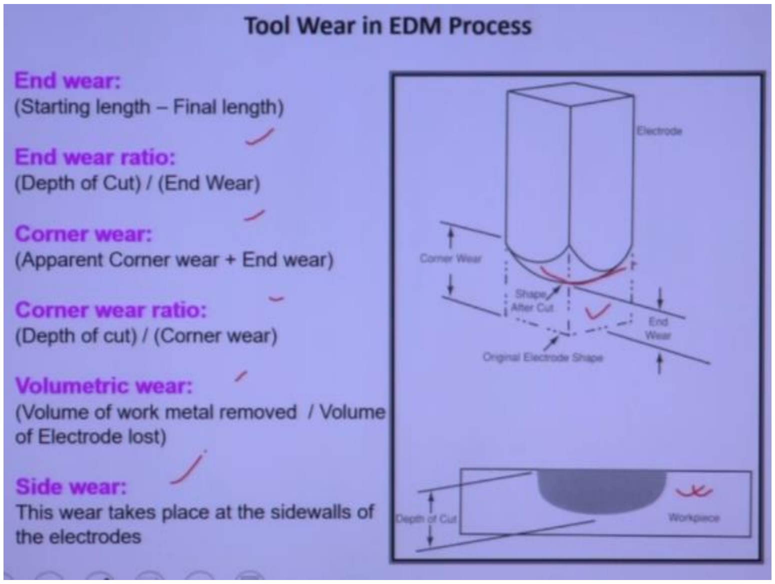

So these are the different kinds of wear. So this is the corner wear. There is a end wear is there. Length is shortened. This is the this kind of shape actually it is generates okay. So using this error erroneous tool you will get this kind of erroneous holes to be made into the workpiece surface. So these are the different wears wear are there end wear, end wear ratio, corner wear, corner wear ratio, volumetric wear, side wear. So these are the different wears are there in case of EDM tool.

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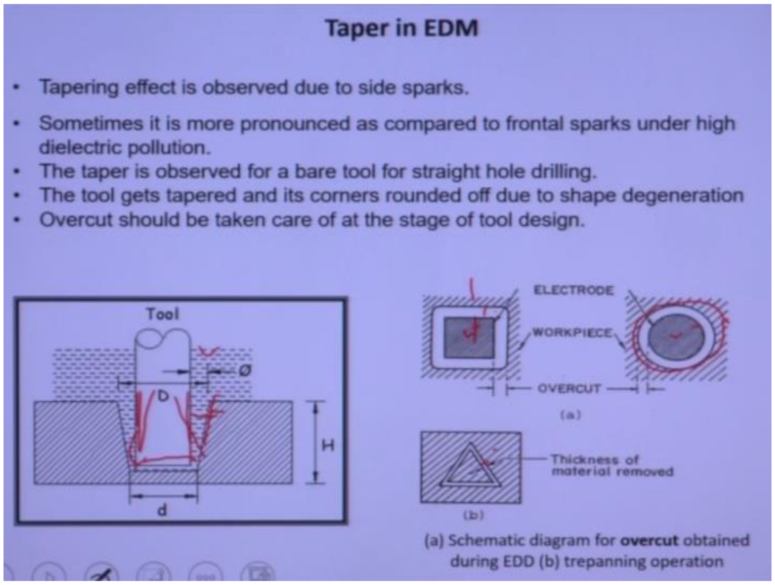

Taper in EDM. So you can see that because of this side spark so this portion of this material actually it is it is most of the times it is in front of this workpiece okay, so in front of this this portion of this workpiece actually it is more time it is in front of the tool. So because of this side spark this kind of taper is generated into the workpiece surface. So to reduce this kind of taper what you can do, you can use a reverse taper okay. So you can use a reverse taper okay.

So this kind of reverse size of the tool can be used to reduce the this kind of taper error or you can use a coated tool. So here this tool this portion and this portion of the tool can be coated keeping this front portion as it is okay. This 2 sides of this tool can be coated so that in that coated tool there will be no side spark will be there. So in that case you can reduce the shape of the this you can reduce the side spark, you can reduce the taper, taperness of this tool okay.

So this much of material although this is the tool dimension so this much of material actually it is removed here okay. So this is the error, overcut error. So this is the overcut. So this is the electrode material. So this diameter here and this much of material is removed from the workpiece. So this is the overcut error.

So this the thickness of this material is removed from the workpiece although it is not wanted. So tapering effect is observed due to the side sparks, here we have discussed now. Sometimes it is more pronounced as compared to the frontal spark under high dielectric pollution. The taper is observed for a wear tool for a straight hole drilling. The tool gets tapered and its corner round off due to the said degeneration. Overcut should be taken care of at the stage of tool design. So you have to design the tool in such a way that this taperness of the tool can be reduced.

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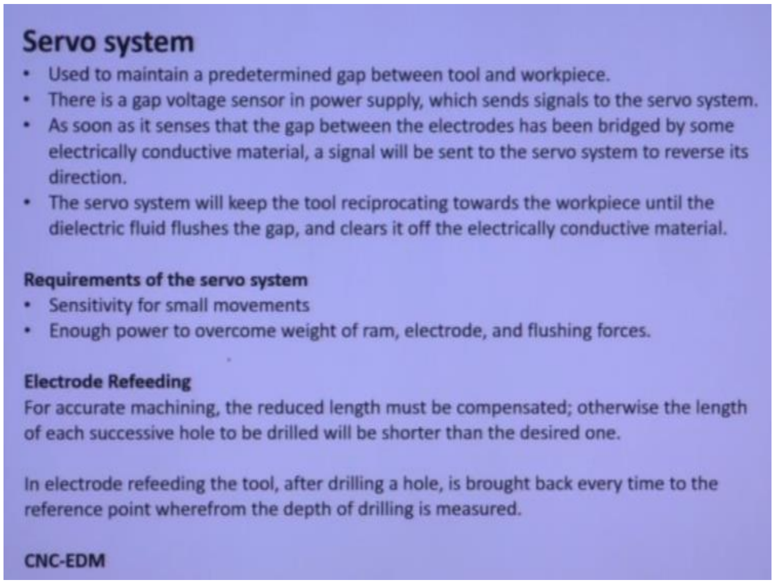

So this servo system. So this is the another component of the EDM system. So it is used to maintain the predetermined gap between the tool and workpiece. There is a gap voltage sensor in power supply which sends the signal to the servo system. As soon as it senses the gap between the electrodes has been bridged by some electrical conducting material, a signal will be sent to the servo system to reverse its direction.

The servo system will keep the tool reciprocating towards the workpiece surface so that this whatever debris materials or debris particles are there can be flushed out and with the dielectric fluid and it clears out clears it off the electrically conducting material. So requirements of the servo system are sensitivity for a small movement and enough power to work on the weight of the ram, electrode, and flushing forces.

So electrode refeeding to accurately machining the reduced length must be compensated. So there is a tool wear tool wear is there in EDM process for accurate machining. So whatever the reduced length of the tool can be compensated. Otherwise the length of each successive hole to be drilled will be shorter than the desired one. So in electrode refeeding the tool after drilling a hole is brought back every time to the reference point wherefrom the depth of drilling is measured.

So there is a reference point is there so after every drilling we have to move to the tool towards the reference point and you have to check how much length of the tool is actually reduced okay. So if there is a tool wear rate is there, tool wear is there in subsequent machining using the same tool you will see the smaller depth of cut okay so reduce that you have to come you have to compensate whatever the tool length compensation is there whatever tool length is reduce, that should be compensated and for that actually you have to bring the tool into a reference point and you have to check how much the distance of the tool is actually reduced. So you have to move that extra portion into the workpiece using that tool so that this exact dimension of the tool workpiece maybe machined. So there is a CNC-EDM is there.

You can move the table in such a way that any complex surface can be made by this EDM process. So you can reduce the tolerances further and you can increase the you can increase the accuracy of the tool. Also in CNC system there is a automatic tool changer is there. From that automatic tool changer you can you can keep many number of many different varieties of tools you can keep and during machining you can utilize different kinds of tools from that automatic tool changer and you can utilize that during machining itself.

Now we are going to discuss the analysis of resistance capacitor circuit or relaxation analysis of that relaxation circuit.

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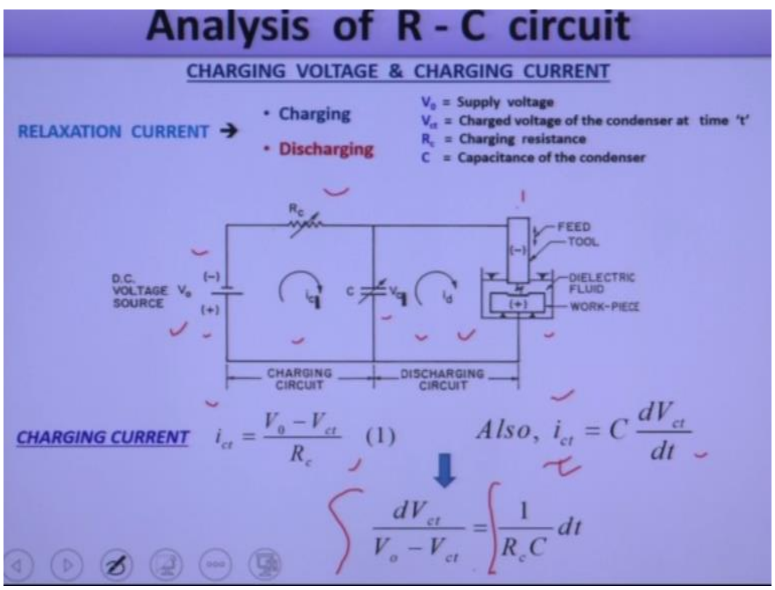

So what I told that in that RC circuit there are charging circuit there is a discharging circuit is there. So you are applying the voltage V0, this is the source voltage V0. It is a DC voltage. So this is the negative terminal here, this is the positive terminal. So there is a charging resistance is there that is Rc charging resistance. Current flowing through the charging circuit that is the i ct, i ct is the current flowing to flowing through the charging circuit. So that is the i ct, c is the capacitance of the capacitor here and V ct is the charged voltage of the capacitor.

Now after charging there is a discharging circuit so there is a current flowing through this discharging circuit is id and resistance in between this tool and tool and workpiece this dielectric fluid is there. The dielectric fluid resistance is Rs here okay. So there are 2 circuit, one is the charging circuit, another one is the discharging circuit. Now this tool is actually fed towards the workpiece surface as in the servo system here you can see.

This tool is actually connected to the negative terminal, so it is cathode here and workpiece is actually connected to the positive terminal so this is anode here. So first in the charging circuit what are the equations are there we shall discuss. The current through the charging circuit it is the V0 is the voltage applied, force voltage applied minus V ct is the charged voltage divided by this Rc will give the current flowing through the charging circuit.

So Rc is the resistance to the charging circuit, resistance of the charging circuit. Now this i ct also we can retain you can write in different form, i ct equal to C into dV dt. So this V, V is the charged voltage dV ct by dt okay. So now this i ct is returning to different form. Now you can equate this i ct with this i ct okay. After equating so you will get this in this form. After simplification you will get dV ct divided by V0 minus V ct equal to 1 by Rc into C into dt. Now integrating both the sides.

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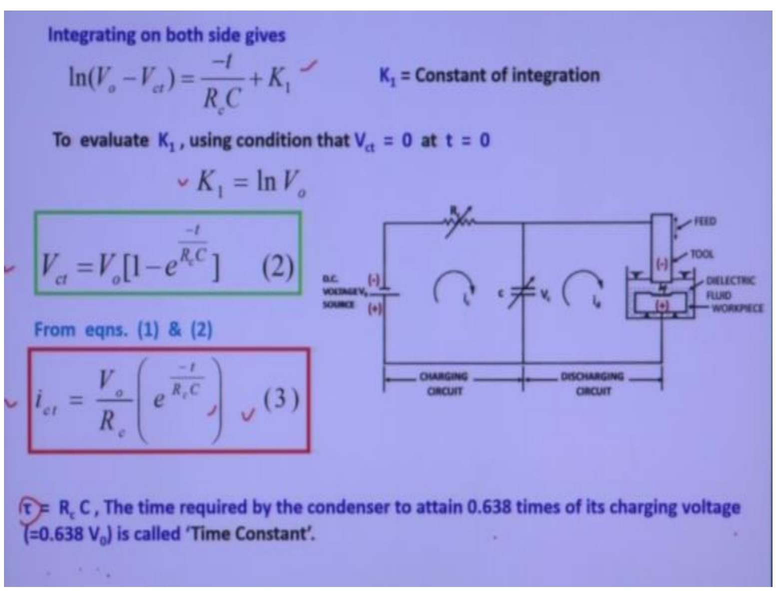

So after integration you will get this kind of form. So this is n log V0 minus V ct equal to minus t by Rc into C plus K1, K1 is the constant of integration. This K1 value can be calculated from this using this condition that this charged voltage V ct equal to 0 at time t equal to 0. So if you put equal to 0 there then you will get this K1 value of this K1 equal to ln V0 logarithm of V0. Now you put this value of this K1 into this equation.

After putting this value of K1 into this equation you will get in this form V ct equal to charged voltage equal to V0 is the source voltage into 1 minus e to the power minus t by Rc into C. So V ct is the charged voltage equal to V0 is the source voltage 1 minus e to the power minus t by Rc into C. So from equation 1 and 2 so now if you put this value of this V ct into this equation, so this value of V ct into this equation you will get the charging current.

So this charging current is equal to V0 minus Rc V0 by Rc e to the power minus t by Rc into C. So this is the charged current charging current into the charging circuit and is the charged voltage of the capacitor. So this is the charged voltage of the capacitor, this is the charging current into the charging circuit.

So in this equation you can consider this Rc into C equal to tau so this time required by the condenser to attain 160% of this charging voltage or current required time required for the charging so this tau is equal to this time constant, tau is equal to time constant, time constant is defined as time required by the condenser to attain the 0.68 times of this charging voltage is called the time constant okay 0.638 into V0 will give the time constant.

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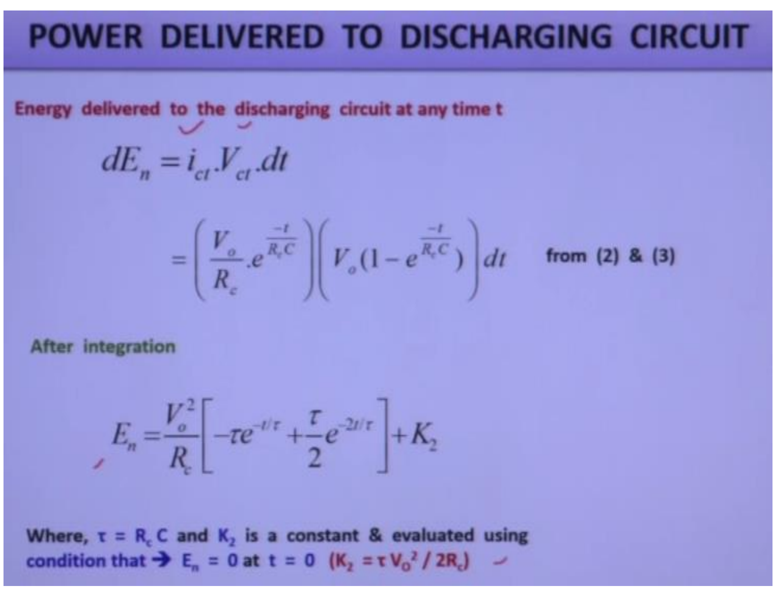

So power delivered to the discharging circuit. So how much power is delivered to the discharging circuit so it is i ct charging current multiplied by charged voltage of that capacitor into dt with time dt okay. So now you can put this value of this i ct and V ct charged current, charging current, and charged voltage of the capacitor you can put this value.

Now after simplification you will get after integration and simplification you will get this En equal to V0 square by Rc, so Rc is the resistance to the charged circuit minus tau into e to the power minus t by tau, tau equal to Rc into C plus tau by t e to the power minus 2t by tau plus K2. So K2 is the integration constant. So this integration constant can be calculated as energy delivered to the discharging circuit at time t0 equal to 0. So En equal to 0 at t equal to 0. So from there you can calculate the value of this K2 equal to tau V0 square by 2Rc.

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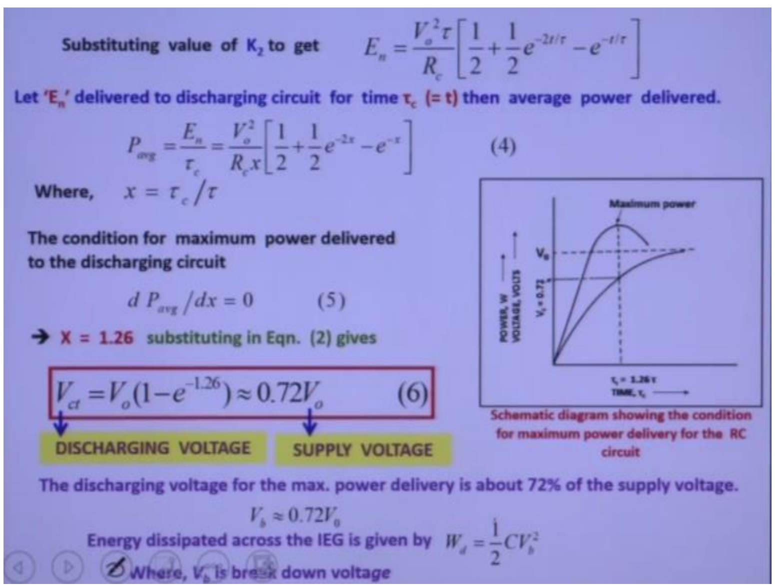

Now if you put the value of this K2 into this equation we will get this En energy delivered to the discharging circuit in this form you can get. So now this energy is delivered to this discharging circuit for a certain time t c, t c equal to t for certain time t which you can write this t c. So without so it is delivered to this discharging circuit for the certain time t c equal to t c. So the average power delivered to the discharging circuit is E n by tau. C n by tau c with a means E n divided by this time tau c so equal to V0 square by Rc into x into half plus half of e to the power minus 2x minus e to the power minus x. So this x is here t by t by tau.

So this x is actually it is t equal to tau c by tau. So now for condition of for the maximum power delivery it should be d P average by dx equal to 0. So if we now take a derivative with respect to x of this equation 4 now if we equate this one this equation equal to 0 now we will get this this condition for the maximum power delivery to the discharging circuit. So after simplification after doing this one we will get this x value of this x equal to 1.26.

Now you put the value of this V ct equal to V0 1 minus e to the power so in this equation so V ct equal to V0 1 minus e to the power minus t by tau t by minus t by Rc into C. So here this t by Rc into C equal to 1.26. Now put this value of this 1.26 here and we will get this 0.72 into V0. So when this discharging voltage is 72% of this source voltage then maximum power delivery occurs when discharging voltage is 72% of the source voltage or supply voltage then maximum power delivery occurs.

So energy dissipated in the interelectrode gap is given by energy dissipated into the interelectrode gap is given by half CVb square. C is the capacitance of this capacitor and Vb is the breakdown voltage okay. So this where Vb is the breakdown voltage here. So how much energy dissipated through the interelectrode gap it is half CVb square.

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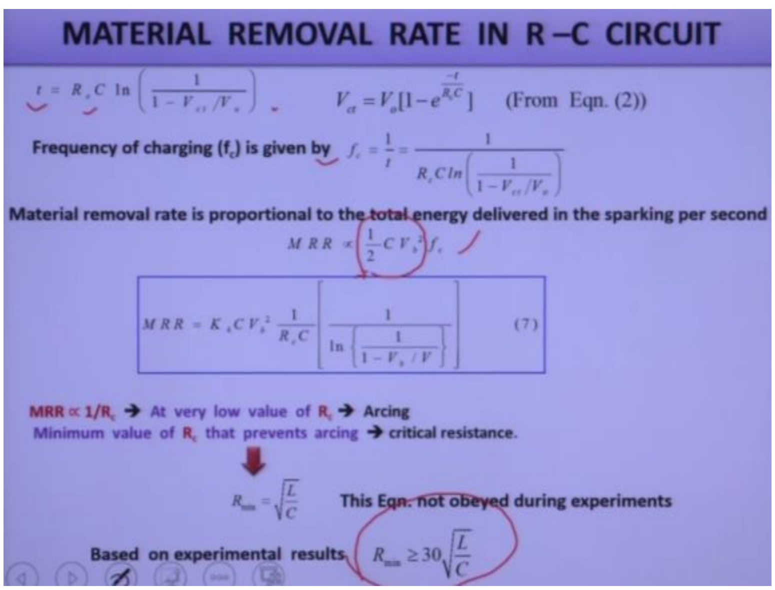

So now we can write this equation so this t we know here so this equation 2 can be written in this form t equal to t you can you can write in this form here. So from this equation it is converted to this in this form t equal to Rc into C ln 1 by 1 minus Vct by V0. Frequency of charging can be given as f c equal to 1 by t equal to 1 by Rc into C ln 1 by 1 minus Vct by V0 okay. So material removal rate is proportional to the total energy delivered to the sparking and per second how many. So energy delivered per second and how many sparks are there per second this is f c okay. So material removal rate per spark actually this much material removal is there half CV square this much energy required and how much energy is how much how many sparks are there in per second it is given by this f c.

So f c already we have calculated here. So I can put M R R equal to in this form K4, K4 is the constant into C Vb square into 1 by R c into C 1 by ln 1 by 1 minus Vb by V okay. So material removal rate is proportional to the Rc inversely proportional to the Rc. So now at very low value of this Rc very low value of this charging resistance your material removal rate will be very high but if we go beyond a certain value there will be a arcing will be there okay. So minimum value so there should be a minimum value of Rc to avoid this arcing. So this is called actually critical resistance of this charging circuit. So this is called critical resistance.

So this minimum value of this critical resistance minimum value of critical resistance can be calculated can be given as root over L by C, L is the inductance, C is the capacitance here. So during experiment actually this equation does not follow. So experimentally it is found that this critical resistance is equal to greater than equal to 30 into root over L by C okay. So it can be this from experimental condition actually this critical resistance, value of this critical resistance can be modified okay.

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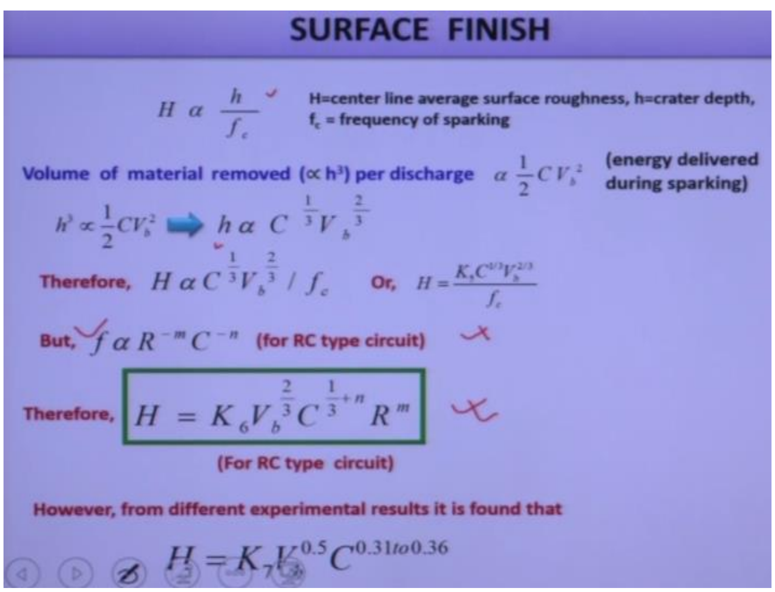

So now what should be the surface roughness. So you can see that during EDM process this kind of thousands of craters are formed. So this crater height actually is proportional to the surface finish you can consider and we know this if we increase the frequency of current your surface finish surface roughness actually reduces. So this frequency of current is inversely proportional to the surface roughness okay. So more frequency of current surface finish will be less okay.

So H this surface roughness center line surface roughness is proportional to the capital H depth of the crater divided by f c frequency of this sparking. So volume of material is removed. So this volume of material is removed. So this is the depth of this crater that is H. So volume of material removed it can be volume of material removed it can be given as h cube so this h cube per discharge is proportional to the half CV b square so h cube equal to half CV b square V b is the breakdown voltage or H can be given as C to the power of 1 by 3 V b to the power 2 by 3. So now this H value of H can be put into this equation so H equal to H proportional to C to the power 1 by 3 V b to the power 2 by 3 divided by f c or H can be written as as a constant K5 H equal to K5 C to the power 1 by 3 V b to the power 2 by 3 divided by f c.

So for RC type circuit this f can be written as R to the power minus m C to the power minus n okay so now putting this value of this frequency into this equation now this final equation for this surface finish can be written as K to the power 6 V b to the power 2 by 3 C to the power 1 by 3 plus n R to the power m. This is for RC type circuit. So however from the different experimental results it is found that this H equal K 7 V to the power 0.5 C to the power 0.31 to 0.36. So this is the final expression for the surface finish in case of EDM process where this craters, semispherical craters are generated.

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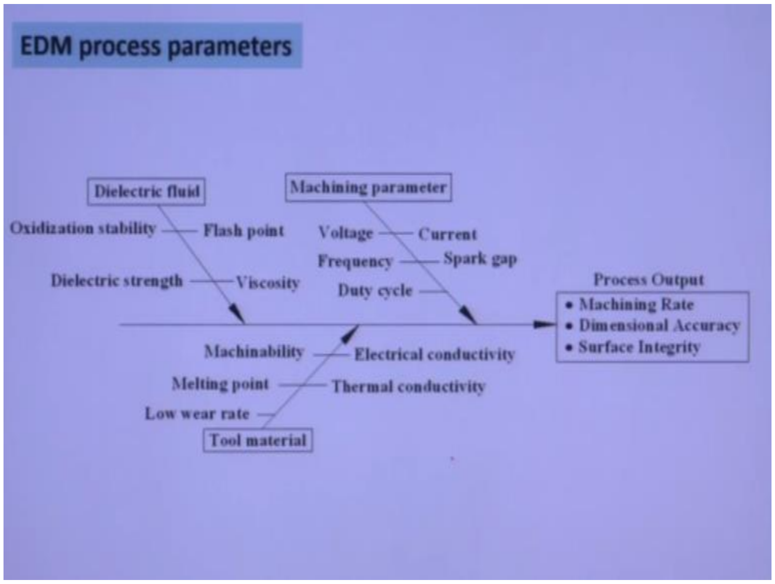

Now there are different parameters for the EDM process. So this parameters are dielectric fluid. So this dielectric fluid oxidation stability flash point, dielectric strength of this dielectric fluid and viscosity of this dielectric fluid are the components of or parameters for this EDM process. The machining parameters are the voltage, current, frequency of current, and spark gap or interelectrode gap, and duty cycle. So this duty cycle is one time by pulse time. So these are the machining parameters current, voltage, frequency of current, interelectrode gap, and spark gap, and duty cycle these are the machining parameters.

Then tool material, tool material machinability, melting point of this tool material, wear rate of this tool material, electrical conductivity, thermal conductivity of this tool materials are also parameters for this EDM process. Now what are the outputs are there? Output for EDM process are material removal rate or machining rate, dimensional accuracy, and surface integrity. These are the different outputs for this EDM process. So effect of current and spark frequency. So with an increase in the current you can see here in this figure with an increase in the current results in the increased material removal rate.

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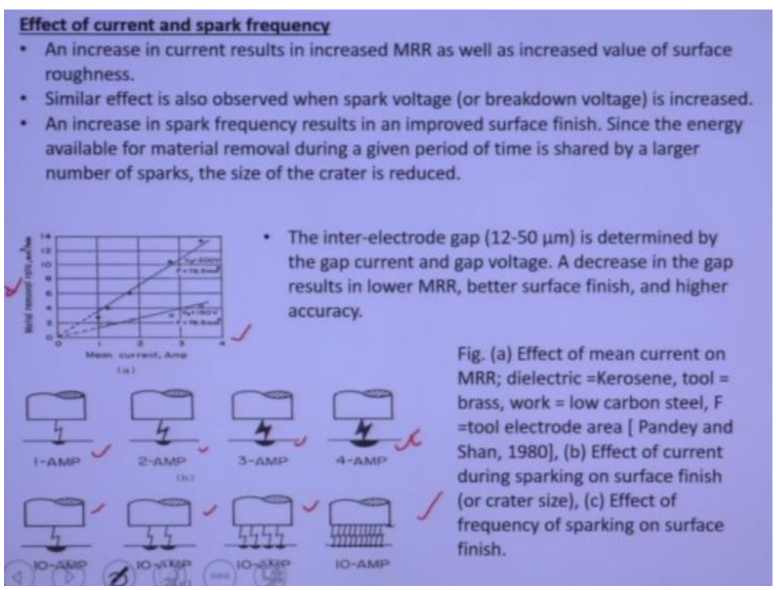

So here material removal rate you can see here with the increase in current, material removal rate increases. Also you can see that with the increase in the current this surface roughness also increases. So similar effect also observed when the spark voltage or breakdown voltage is increased. If we increase the breakdown voltage your material removal rate will also increase. Also your surface roughness also will be means will also be increased with the increase in the current. So this is the explanation here. So if you increase the current here you can see this crater dimensions actually this diameter of this crater and depth of crater also increases.

As the diameter of the crater and depth of craters are increases you will get bigger size crater so obviously your material removal rate will increase because of this bigger size crater but at the same time as the crater depth also increases so your surface roughness will also increase because of this bigger size crater and also breakdown means if we increase the breakdown voltage of this dielectric fluid in that case also your charge energy will be more in a spark so your material removal rate will also be more and bigger size crater will be generated because of generation of the bigger size crater your material removal will be more and surface roughness will be more.

Now second one is the an increase in the spark frequency results in the improved surface finish since the energy available for material removal during a given period of time is shared by a large number of sparks and size of the crater is reduced.

So here you can see for a same current of 10 ampere here one frequency in one second, here 2 number of frequency is 2, here number of frequency is 3, and here you can see many number of frequency sparks are actually generated. Or you are increasing the frequency of current. So increase in frequency of current means number of sparks, sparks again actually increases so we have means we have we have kept same amount of current 10 ampere of current.

As the number of sparks actually increases number of sparks increases but your energy level is constant for the same energy level more number of sparks are generated so that is why same energy is distributed among the more number of sparks. So surface finish will be reduced in this case but material removal rate also will be reduced.

So material removal rate and surface finish will be reduced if we increase the or surface roughness will be reduced and we will get better polished surface if we increase the frequency of current. So this interelectrode gap is determined by the gap current and gap voltage. So there is a gap voltage sensor is there. A decrease in the gap results in a lower material removal rate and greater surface finish so if you reduce the gap interelectrode gap it results in a lower material removal rate, greater surface finish, and higher accuracy.

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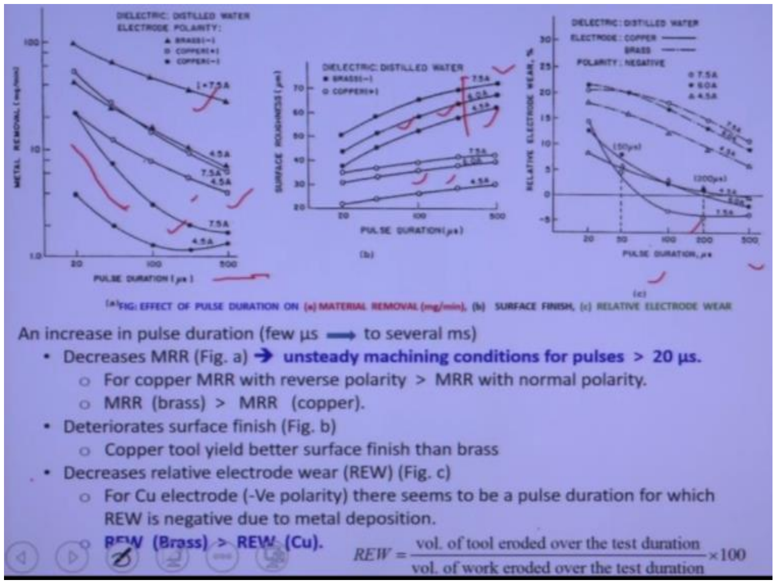

Now an increase in the pulse duration from few microsecond to the several millisecond so if you increase the pulse duration your material removal rate, this material removal rate actually decreases with the increase in the pulse duration. So this material removal rate decrease because unsteady machining conditions for pulses for more than 20 millisecond. So you can see this for copper so here for copper material removal rate with reverse polarity so with reverse polarity we will see that it is material removal rate is more, with the copper with the normal polarity.

So with copper you will see that if we put the reverse polarity we will get more material rate than the normal polarity. So material removal rate for this brass is higher than this copper. So with the increase in the pulse duration you will see your surface roughness actually increases your or surface finish actually deteriorates. So surface roughness increases.

Also with increase in the current your surface finish also with increase in the current your surface roughness also deteriorates or surface roughness increases or surface finish deteriorates or surface roughness increases. So copper tool here you can see this is the this is for this copper tool and this is for this brass tool. So copper tool is better surface finish than brass tool.

So if we need better surface finish you have to go for this copper tool. So here you can see this relative electrode wear rate if we increase the pulse duration from 50 to 200 or 20 to 500 microsecond you will see this relative electrode wear rate also decreases. Electrode wear rate is volume of material is removed from the tool by divided by the volume of material removed from the workpiece multiplied by 100 will give the electrode wear rate. So if we increase the pulse duration your electrode wear rate also decreases. So for some portion of this in this case for some portion so for copper electrodes for this one is the copper electrode, negative polarity there seems to be pulse duration for same there seems to be a pulse duration for which electrode wear rate is negative due to the metal deposition. So for this pulse duration of 50 to 200 cycles for copper electrode there is a negative electrode wear rate or there is a deposition of this material into the tool itself so electrode relative electrode rate electrode wear rate actually negative in this case so there is a deposition of this material is there. So relative electrode wear rate is more in case of brass than this so this is the brass here. So this is the electrode wear rate is higher in case of brass than the copper.

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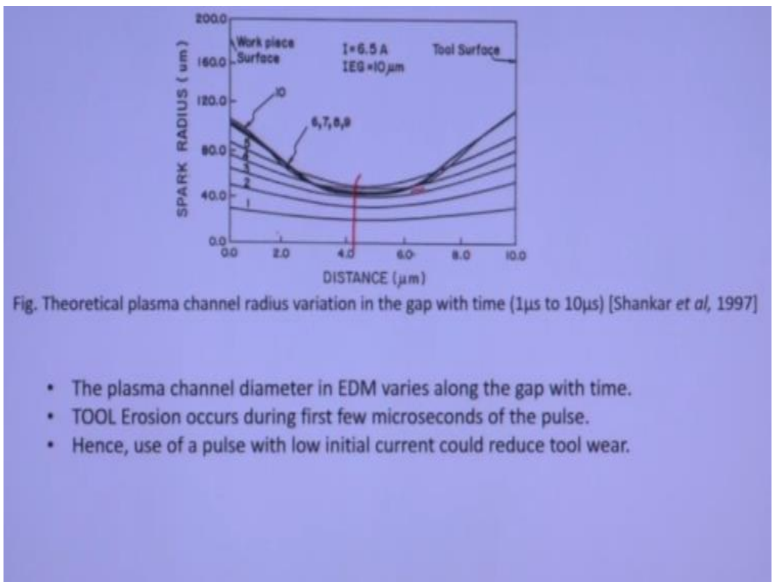

So here you can see for different microsecond this diameter of this spark or ionization channel you can see how it is varying from 1 second, 2 second, 2 microsecond, 3 microsecond, 5 microsecond, up to 10 microsecond, at different time how this this is the simulation results how this diameter of the plasma channel actually varies with time. So here there is a (()) 1:34: 15 and after that it increases in both the sides. So this plasma channel diameter in EDM varies along the gap. So along this interelectrode gap this plasma channel diameter varies with time.

Tool erosion occurs during the first few microseconds. So that is why for first few microsecond because of this tool erosion occurs for the first few microsecond so that is why you have to use lesser current to the tool for the first few microsecond to reduce the tool wear. So hence use of the pulse with low initial current could reduce the tool wear.

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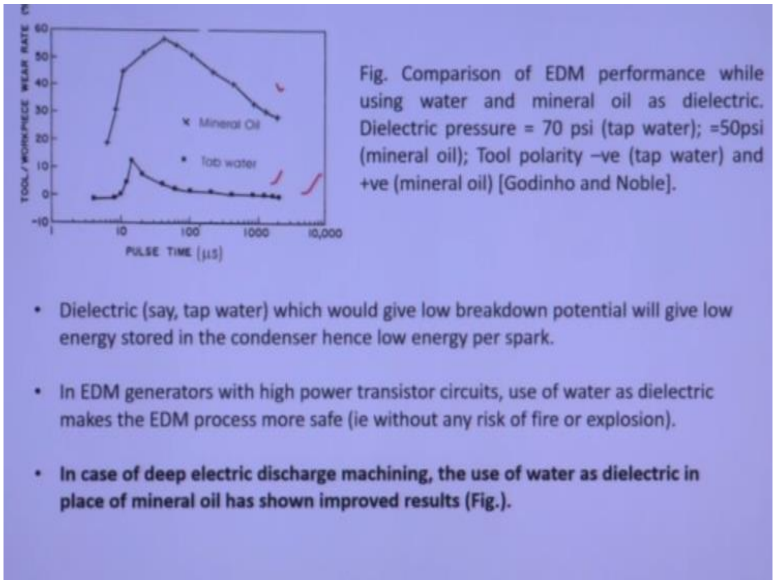

So here there is a comparison with the mineral water with the tap water. So you can see with the pulse time tool wear rate increases and it attains a certain value maximum value then it reduces. So with pulse time this with the increase in the pulse time this tool wear rate also increases. So mineral water actually it gives higher tool wear rate than the tap water. That is why tap water actually considered to reduce the tool wear rate.

So dielectric say tap water which would give lower low breakdown potential will give low energy stored in the condenser hence low energy per spark. In EDM generators with high power transistor circuit, use of water as dielectric makes the EDM process more safe without any risk of fire or explosion. In case of deep electric discharge machining, the use of water as dielectric in place of mineral oil has shown improved results.

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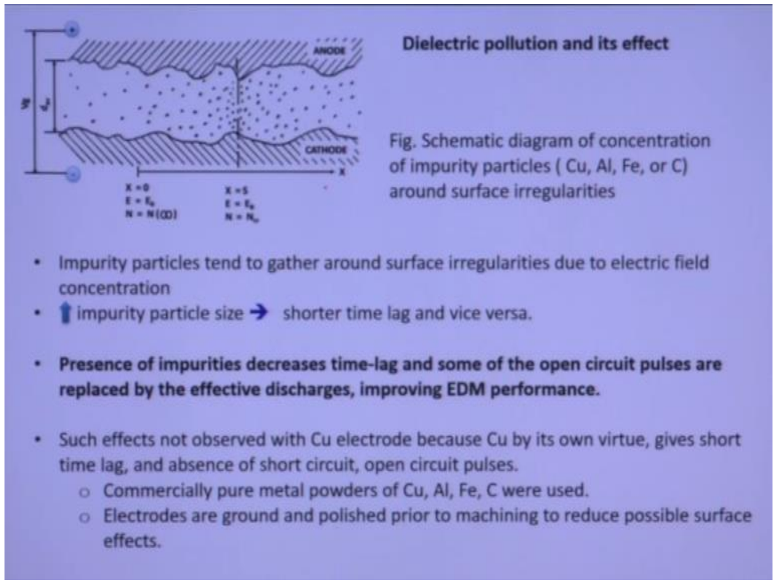

So the topic is here dielectric pollution its effects. Dielectric pollution because of this debris actually if it is flushed out properly it concentrates where there is a minimum gap is there, minimum interelectrode gap is there so because of this higher electric field there this whatever debris particles actually they actually concentrate into the minimum interelectrode gap.

So this is the schematic diagram of the concentrator of the concentration of impurity particles. So this is copper, aluminium, iron, or carbon around the surface irregularities. So in this case this kind of powders, metallic powder actually it is used to check their if we mix this metallic powder how this EDM process affects. So this impurity particles it is mixed externally into the dielectric fluid. So with the increase in the with the increase in the this particles there impurity particles tend to gather around the surface irregularities due to the electric field concentration there.

So with the increase in the impurity particle size shorter time lag, so if you increase the impurity particle size there will be a shorter time lag will be there okay. So presence of impurities decreases the time lag. If we mix the impurities it will decrease the time lag there and some of the open circuit pulses are replaced by the effective discharges.

So it will improve the EDM performance because some of the open circuit pulses are replaced by the effective discharges so it improves the EDM performance. So it is advantageous to mix some kind of impurity particles, impurity metallic powder in the dielectric fluid so that this impurity particles concentrate at the interelectrode gap where minimum interelectrode gap okay. So it decreases the time lag. Time lag is after this breakdown voltage is achieved so this dielectric fluid actually takes certain time it this circuit this capacitor takes certain time to discharge.

So it depends on the actually dielectric fluid, property of the dielectric fluid. So if we mix this dielectric fluid with some metallic powder, this ignition delay time also reduces. So if we reduce the if this ignition delay time is reduced some of the open circuit pulses are replaced by the effective discharges improving the EDM performance.

Such effects not observed with copper electrode because this copper by its own virtue gives short time lag and absence of short circuit and open circuit pulses. So commercially pure metal powders are copper, aluminium, iron, carbon, these are used. So electrodes are ground and polished prior to the machining to reduce the possible surface effects.

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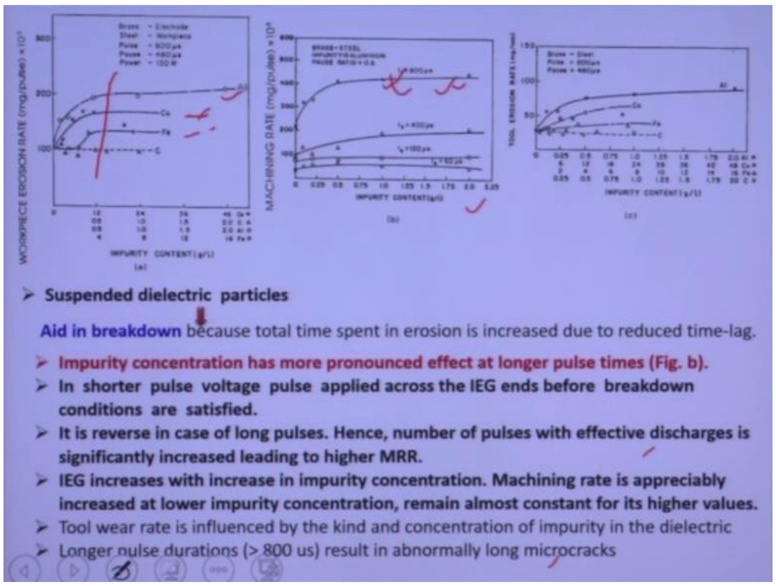

So now here you can see with the increase in the impurity particle you can see workpiece erosion rate also increases. So this is for aluminium, copper, iron, and carbon. So these are the 4 impurity particles are actually mixed up. So you can see with aluminium powder maximum material removal from the workpiece actually happens and with the increase in the impurity particle concentration initially for few concentration so if we increase the impurity particle initially with the increase in the impurity particle concentration, this workpiece material removal rate increase but after that it becomes actually stalled, so it stall means there is no change in the material removal rate.

So with the increase in the impurity content here you can see this machining rate also increases but with the current with the pulse current, if we increase the pulse current you can see here this machining rate also increases. So this suspended dielectric particles aid in breakdown because of this total time spend erosion is increased due to the reduced time lag. So if we if you can reduce the time lag so whatever the total time is there total pulse time is there then most of the time it is used for the machining. So most of the time spent is on the workpiece surface is by erosion only. So impurity concentration has more pronounced effect at longer pulse time so you can see it has a higher pronounced means pronounced effect at longer pulse time.

Shorter pulse voltage applied across the interelectrode gap ends before the breakdown conditions are satisfied. It is reverse in case of long pulses. Hence number of pulses with effective discharges is significantly increased leading to the higher material removal rate.

Interelectrode gap increases with increase in the impurity concentration. Machining rate is appreciably increased at lower impurity concentration and remain almost constant for its higher values. Tool wear rate is influenced by the kind of kind and concentration of impurity in the dielectric. Larger pulse duration, more than 100 microsecond result in the abnormality long microcracks. So microcracks are generated if we increase the larger pulse current.

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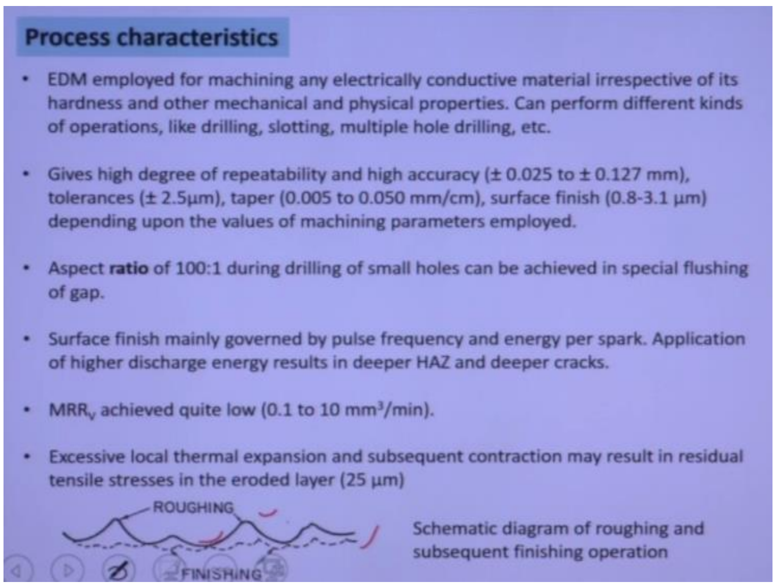

So process characteristics, EDM is employed for machining any electrically conducting material irrespective of its hardness. So hardness does not matter because electrical energy in its direct form it is used, any kind of material whether it is very hard or not it does not matter. Any kind of material can be machined by this process. So it does not depend on the hardness and other mechanical and physical properties of this material. So it can perform different kinds of operation like drilling, slotting, multiple hole drilling, etc. So it gives high degree of repeatability and high accuracy that is plus minus 0.025 to plus minus 0.127 this much of repeatability and accuracy can be achieved. With tolerances plus minus 2.5 micron and taper 0.005 to 0.05 mm/cm. Surface finish 0.8 to 3.1 micron surface finish can be achieved by this EDM process. Depending upon the values of the machining parameters are employed. So these values will change depending on the values of the machining parameter.

Aspect ratio means length of the hole to the diameter of the hole as much as 100:1 during drilling of small holes can be achieved in special flushing of gap. Surface finish mainly governed by the pulse frequency and energy per spark. So if we increase the energy per spark your material removal rate will increase. If you reduce the frequency of current then also your material removal rate will increase, but if we increase the frequency of current your material removal rate will decrease, your surface finish will improve.

So surface finish mainly governed by the pulse frequency energy per spark. Application of higher discharge energy results in deeper height affected zone and deeper cracks. So if we increase the discharge energy then your heat affected zone will be increased and it will generate deeper cracks into the workpiece surface. So material removal rate is achieved quite low in case of EDM process, it is 0.1 to 10 mm cube per minute. So EDM surface you can see there is a thermal residual state is generated because of this local thermal expansion and subsequent contraction may result in residual tensile stresses in the eroded layer.

So residual state is generated because of this thermal expansion and contraction of this EDM machine surface. So schematic diagram of the roughing and subsequent finishing operation. So this is the roughing operation by using this EDM process. This kind of craters are generated, hemispherical craters, and this is the machine surface, finished surface by using EDM.

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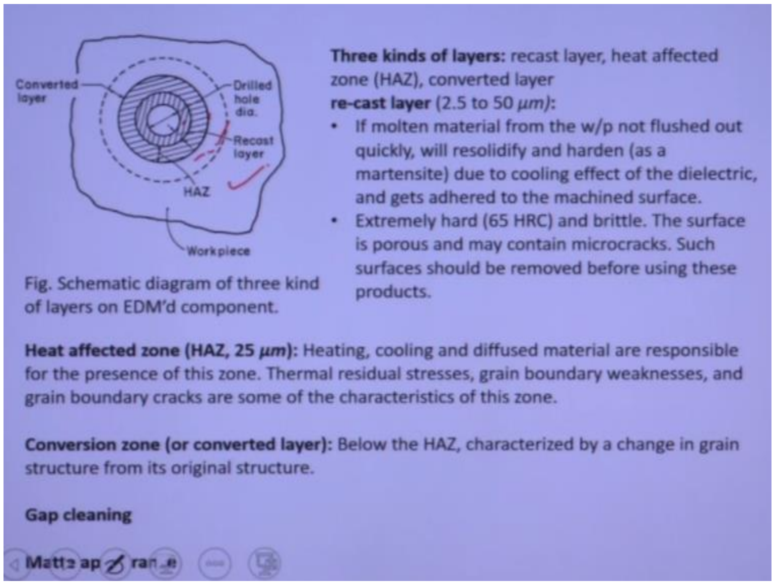

So there are 3 means after EDM, EDM machine surface you can see on the microscope there are 3 different zones are there. First one is the recast layer. So whatever molten material is there, molten material and vaporized material is there so what happens when sparks occur then pressure is very high so around 200 atmospheric pressure is generated so this molten material cannot flush out but at when this spark disappears then pressure actually releases, immediately the pressure releases so during this off-time of the spark pressure immediately the spark this pressure releases.

As the pressure releases whatever molten material is there it comes outside from the from the crater and it resolidifies if the proper flushing is not there, it resolidifies on the already machined surface suppose you are making hole. So it is resolidifies at the internal surface of the already machined surface. So if molten material is not from the workpiece is not flushed out properly or quickly will resolidify and harden as a martensite so it is a there is a martensite formation is there.

So it resolidifies and harden due to the cooling effect of the dielectric and it gets adhered to the already machined surface, already machined EDM already machined surface by the EDM. So this hardened material it has a very high hardness around 65 hardness means hardness in Rockwell scale Rockwell C scale and it is very brittle. The surface is porous and may contain microcracks. So its surface is porous and it may contain microcracks. Such surfaces should be removed before using these products.

So this surface may be removed before using these products. Heat affected zone means after that recast layer there is a heat affected zone around 25 micron. So heating and cooling and diffused material are responsible for the presence of this zone. Thermal residual stresses, grain boundary weakness, grain boundary cracks are some of the characteristics of this zone. After that there is a converted layer is there.

So first recast layer, heat affected zone, and then there is a converted layer is there. Conversion zone or converted layer below the heat affected zone there is a characterized by the by a change in grain structure from its original structure. So there is a change in grain structure from the original structure there is a this is called converted layer and this is the base material. So EDM surface actually generate this matte type of finish. Because of this matte finish, it has a oil retention capability.

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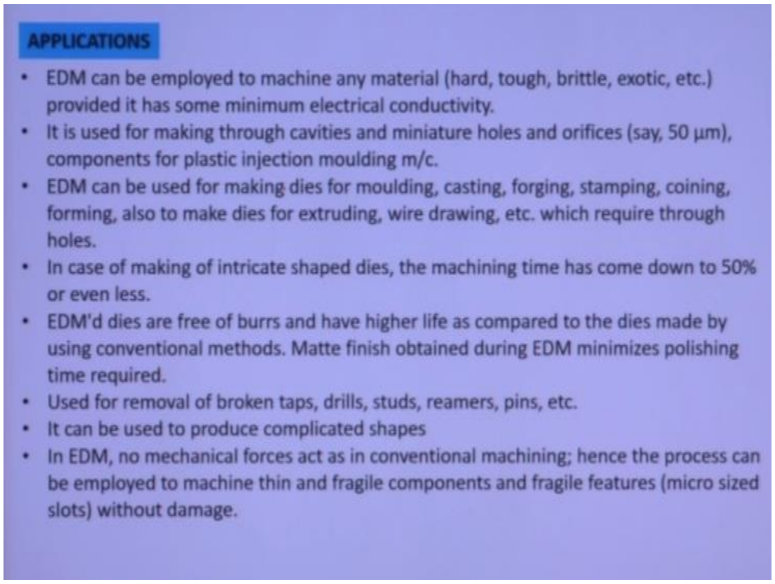

So these are the different applications of this EDM process. EDM can be employed to machine any kind of material, hard, tough, brittle, exotic, etc., provided it has a certain minimum electrical conductivity. So only limitation is that it should have certain minimum electrical conductivity. It is used for making through cavities and miniature holes, orifices say 50 micron, components for plastic injection moulding.

EDM can be used for making dies. So mostly these dye industries actually they prepare this their dye from very hard material using this EDM process. So EDM can be used for making dies, for moulding, casting, forging, and stamping, and coining forming. Also to make dies for extruding, wire drawing, etc., which required through holes. So for extrusion process, for wire drawing process there is a through hole is required. So there in that dye that holes actually is made of made by this EDM process. In case of making of intricate shaped dies, very intricate shaped dies, the machining time has come down to 50% or even less by using this EDM process.

EDM dies are free from any bars. So EDM process there is no bars are formed unlike in conventional process there bars are generated from some drilling operation. So there is no bars are actually formed. So that is why this EDM surfaces are machined surfaces have higher life as compared to the dies made up by conventional methods. Matte finish obtained during this EDM process minimizes the polishing time required. Used for removal of broken taps.

Suppose you are making some taps so that tap actually sometimes it breaks there it is broken there so it is very difficult to remove the tap from the component so what you can do, you can do the EDM operation there. Again you can remove the material from that zone even the tap by machining operation from that zone.

It can be used to produce complicated shapes, any kind of complicated shapes can be generated. You have to make the replica of the surface to be generated on the workpiece surface, then you can make the you can make the workpieces.

In EDM no mechanical forces act as the conventional machining like in conventional machining there is no mechanical forces are used. So hence this process can be employed to machine thin and fragile material. As there is no touching of the tool into the workpiece surface so any kind of fragile and thin materials can be machined or micro size, micro sized slots can be generated by this EDM process without any damage.

So thank you.