Advanced Machining Processes
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Lecture No 10

So in the last lecture is discussed about the electric discharge machining. I mentioned the working principle of electric discharge machining, how the sparking takes place in electric discharge machining? We are mostly interested in sparks rather than the arc because they arc damages the workpiece and the tool both and I mentioned various elements of the EDM machine, we discuss the elements like power supply, tool and workpiece, dielectric supply system and flushing system also. I also mentioned various methods through which dielectric can be supplied in the interelectrode gap that is between the tool and workpiece. You can machine basically 2 types of the shapes one is the through shape another is the blind cavity or blind shapes.

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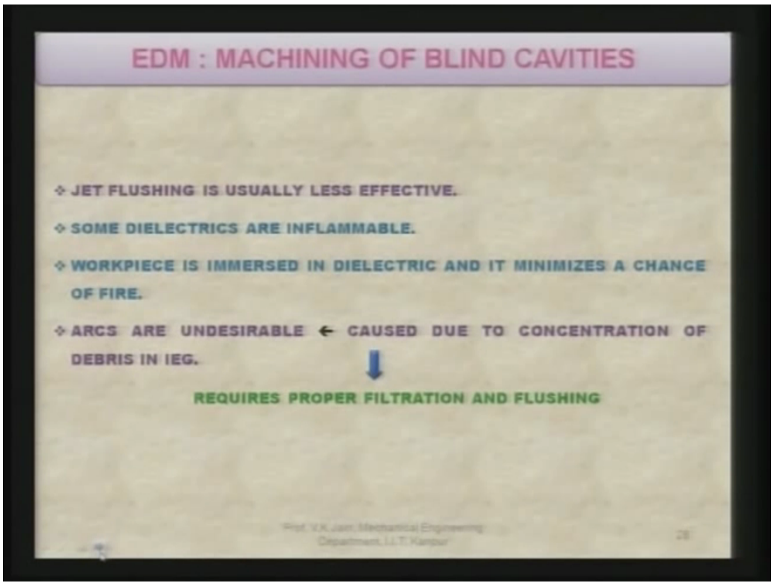

Now in case of blind shapes jet flushing is usually less effective. Some dielectrics are found to be inflammable which is not desirable sometimes it has led to the fire in the machining area or on the machine. Workpiece is immersed in dielectric and it minimises the chance of fire, it also helps in concentration of the heat on the workpiece. Arcs are undesirable because they lead to concentration and lead to the damage of the workpiece and the tool and these arcs are found due to the concentration of debris in the interelectrode gap because the dielectric strength goes down wherever debris are there which are electrically conducting and this results to the arc. It requires proper filtration of the dielectric before resupplying and proper method of supply of the dielectric in the interelectrode gap.

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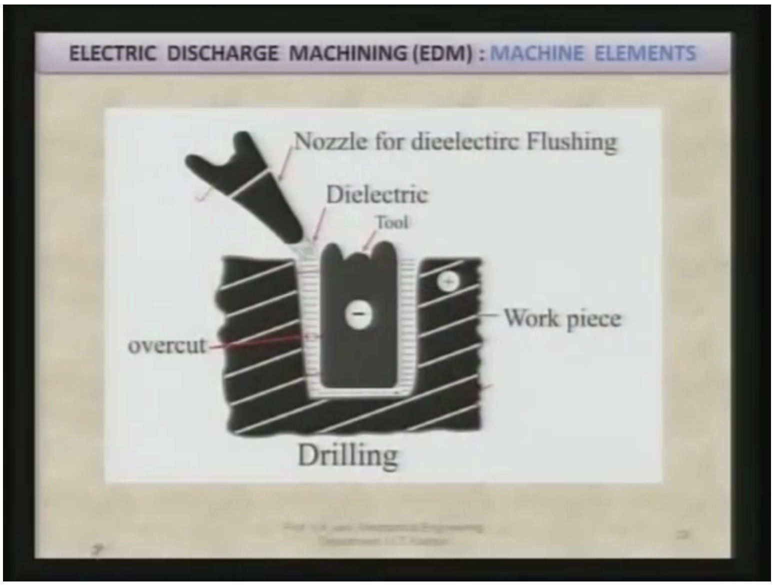

Now you can see here how the flushing takes place with the help of a nozzle for that electric some I as can see here the tool is shown over here which is cathode and workpiece is shown as anode and you can also see the over cut in the side gap and this over cut in the side gap is important and this in this particular case is varying from top to bottom as you can see at the top this is the over cut at the bottom. This over cut reduces and if you go further than it further reduces, so this over cut 1st thing should be uniform for the better qualities of machine cavities and it should be minimum, so that in one pass itself you get the machine components as per your desire; however, normally the machine surface or walls of the machine cavity are tapered because of the wear of the tool.

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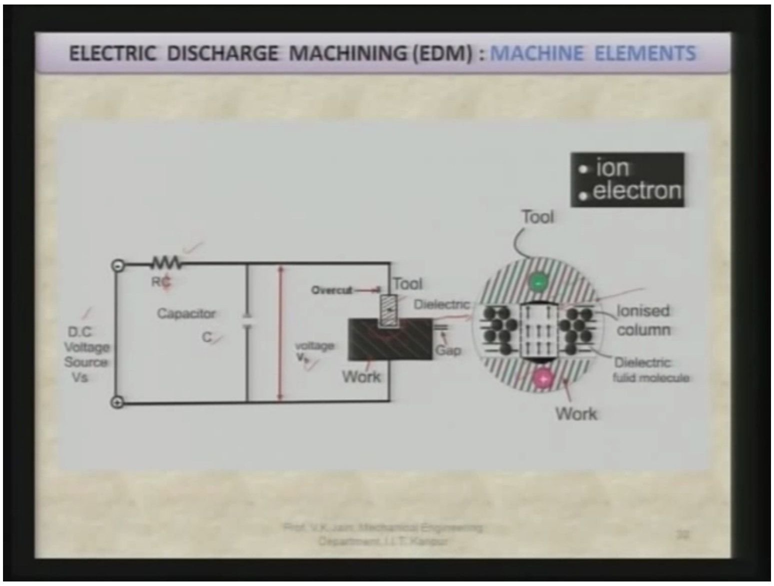

Let us see the RC circuit which I mentioned yesterday while discussing the working principle of EDM process, this is the simple RC circuit which is used, which was used rather in the beginning in the EDM machines. Here is the DC power supply source and the supply voltage is Vs, R is the resistance, resistance in the circuit and C is the capacitor over here that is across the tool and the workpiece and Vb is the breakdown voltage of the dielectric, here you can see the tool is there, workpiece is there and dielectric is being supplied.

The enlarged view of this area is shown over here and you can clearly see the cathode that is the tool, and anode that is the workpiece an ionised column is there, this is the ionised column of the dielectric where you have the electrons and ions both and sparking takes place and you can clearly see small amount of material is removed from the tool and comparatively larger amount of material is removed from the workpiece.

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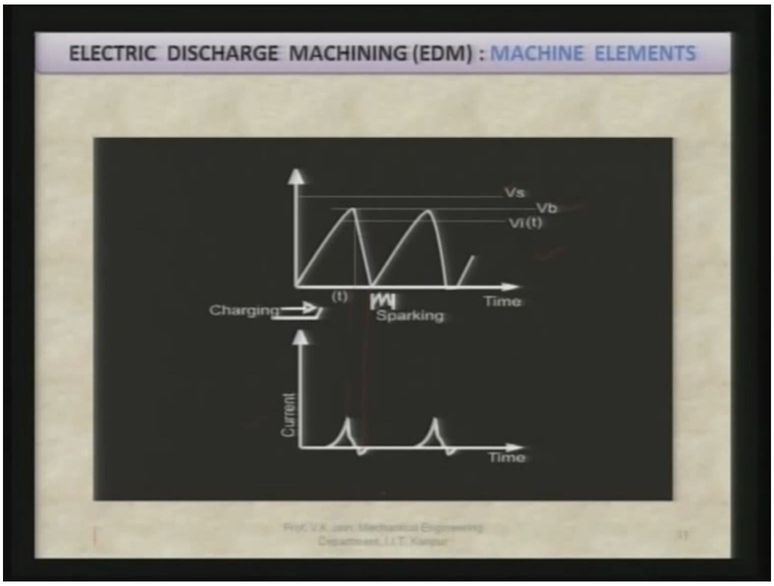

Now in this RC circuit the variation of the voltage and the current is very important as you can see here this is the voltage variation Vs is the supply voltage Vb is the breakdown voltage at which sparking is supposed to take place and I have already mentioned that there is some ignition delay which I showed you in the last class and during which practically there is no sparking, the sparking takes place after the ignition delay and here it is shown that sparking is taking place little later than attaining the breakdown voltage is shown over here and corresponding to this can see here the current pulse, the current flows only in this period after the sparking takes place and that is shown over there and this is the voltage pulses and these are the current pulses in case of RC circuit.

One in modern pulse generator, the pulse shape, pulse size can be controlled and this lot of research work has gone into this direction, so that by controlling the pulse shape you can minimise the wear of the tour and we do not want that there should be any wear of the tool but as a result of the phenomena that occur that is the sparking, some wear of the tool going to take place and that is why various kind of the tool material are tried upon to minimise the wear of the tool because due to the wear of the tool deformation or degradation of the shape of the tool takes place and if the tool shape degrades or changes during machining process then definitely the workpiece shape that you are going to get is also going to change.

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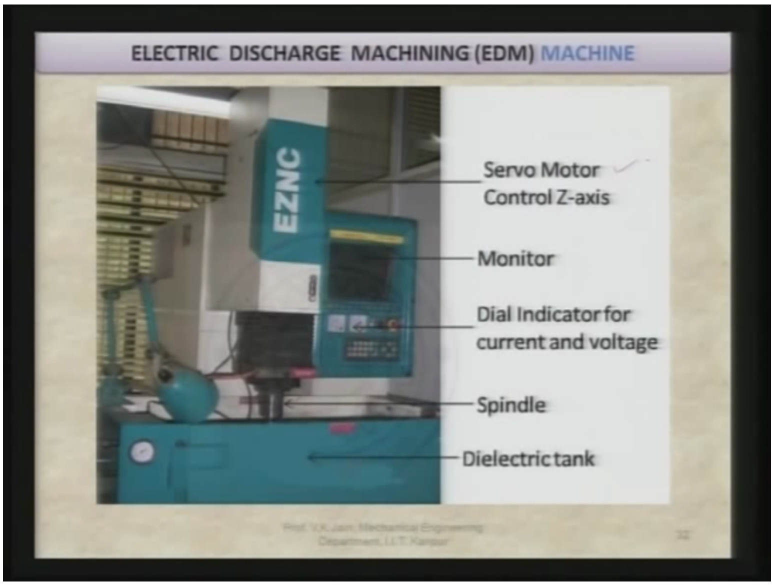

Now this is the actual EDM machine that was purchased from the electronica Pune and you can see the different parts of the machines. Here you can see this is the dielectric tank and here is the spindle which holds the tool and you can see the dial indicator for current and voltage are shown over here and this is the monitor and with the help of the keys over here you can feed the program and z-axis over here is controlled by NC numerical control. X and Y axis you have to control with the help of the hand wheel and here is the servo motor which controls the z-axis through the NC part program.

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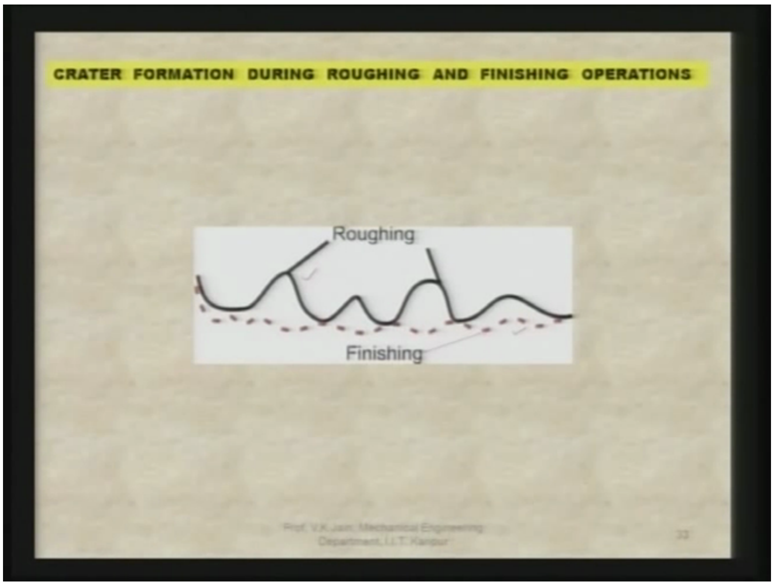

Now as I mentioned yesterday in the last class that you can have roughing pass, you can have finishing pass. In case of roughing pass as you can see over here large craters are formed while in case of finishing pass very small size craters formed, so definitely in case of roughing pass the surface finish, Ra value, Ry value, Rz value are going to be much higher than the finishing pass as you can clearly see over here.

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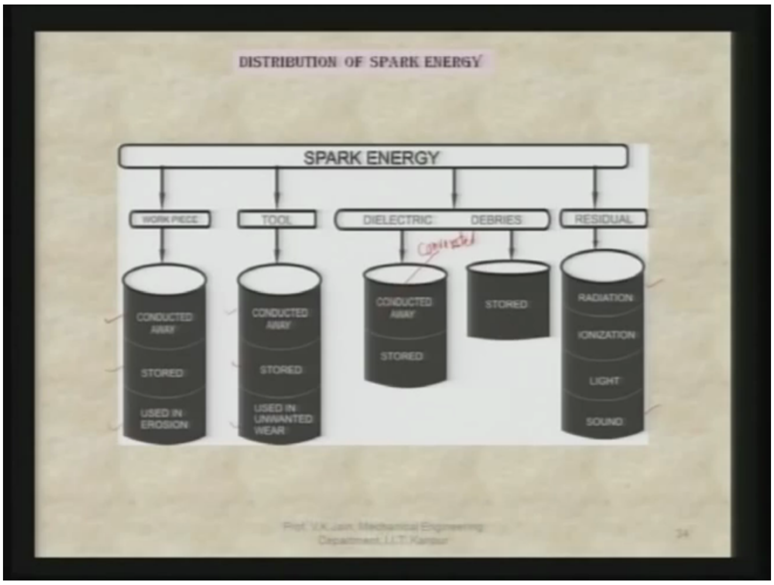

Now the question arises where the energy produced by spark goes out, where are the (()) (8:48) or where are the areas where this particular energy is consumed, so this diagram tells you clearly what is happening to the spark energy. In workpiece where the temperature of the localised area on the workpiece is maximum part of the energy is conducted away within the workpiece itself, part it is stored by raising the temperature of the workpiece and rest of it is used to erode the materials and I mentioned in the last class that the erosion takes place by melting the workpiece material in a localised area and part of it gets vaporised also.

Same way the energy that is concentrated on the tool, part of it is conducted which is stored in the rise in the temperature of the tool and the temperature in the localised area where sparking is taking place on the tool is maximum one where from the part of the material melts out and part of it may get vaporised depending upon the workpiece properties and the temperature or the heat intensity on the tool. So there is the thermal erosion of the tool which is unwanted, we do not want that the erosion of the tool should take place. Same way part of the energy is convicted into the dielectric it should be the convicted not the conducted, convicted.

Part of the energy is convicted in the dielectric and stored in the form of the rise in the temperature of the dielectric and part of this energy is also utilised and vaporisation of the dielectric. Now debris are formed from the workpiece as well as from the tool, the molten material when it solidifies, it remains either in the interelectrode gap or they are flushed out from the interelectrode gap along with the dielectric, so those debris which solidify the molten material that solidify it formed gloviouls, spherical gloviouls and they their temperature is also higher than the room temperature.

So they store some energy in the form of the rise in the temperature, then there are some residuals there is part of the energy losses due to the radiation because the temperature is very high as I mentioned in the last class at it may go many thousand degrees centigrade 4000 - 5000 degrees centigrade theoretically it is more than that also, so the radiation losses are also quite high then part of the energy is utilised in ionisation and some part is utilised in producing the light also because there are sparking due to sparking light is there and which also takes way some energy and some energy is utilised in creating the sound also, so this way this is the distribution of the spark energy during EDM process.

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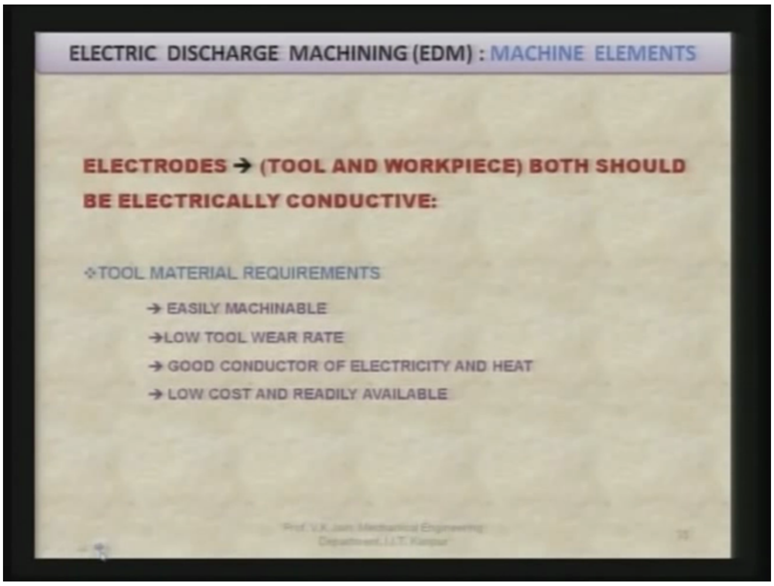

Now electrodes, we have 2 electrodes 1 is the tool another is the workpiece, tool may be mostly it is cathode but sometimes it may be anode also and workpiece mostly it is anode, sometimes it may be cathode also and both should be electrically conducted only then you can have the EDM process and operation. Anyone of them if it is electrically non-conducting then it cannot form a part of the electrical circuit and then EDM process will not take place.

Tool material requirement, which material you should use as the tool material because every material cannot be used as a tool material it should have certain minimum properties that is easily machinable because we are going to make complex shapes components or complex shape tool also depending upon the requirement of the workpiece, so if it is not easily machinable you cannot make accurate complex shape tool, so it should be easily machinable, its tool wear rate should be low cost if tool wear rate is high then the shape of the tool you keep changing continuously and you will not get right kind of the machine workpiece.

It should be a good conductor of electricity as well as heat, it should be good conductor of electricity so that the resistance in the electrical circuit is minimum, so losses for thermal or heat loss are also minimised. It should be good conductor of heat also, so that the heat conducts away and the rise in the temperature of the tool even in the localised area is not very high, so that the wear of the tool will reduce and then its cost should be low definitely it is always desirable and also the material should be readily available.

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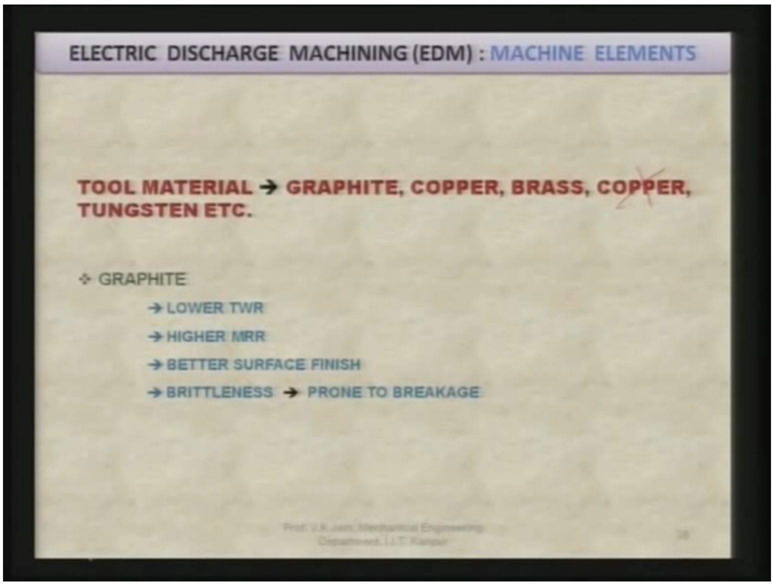

Now tool materials which are commonly used they include graphite, copper, brass, tungsten, et cetera. Graphite has low tool wear rate, high material removal rate, better surface finish but it is brittle in nature, so it is prone to breakage this is the important weakness or this is the weakness of the graphite as the tool material in EDM process, even then this is also commonly used tool material.

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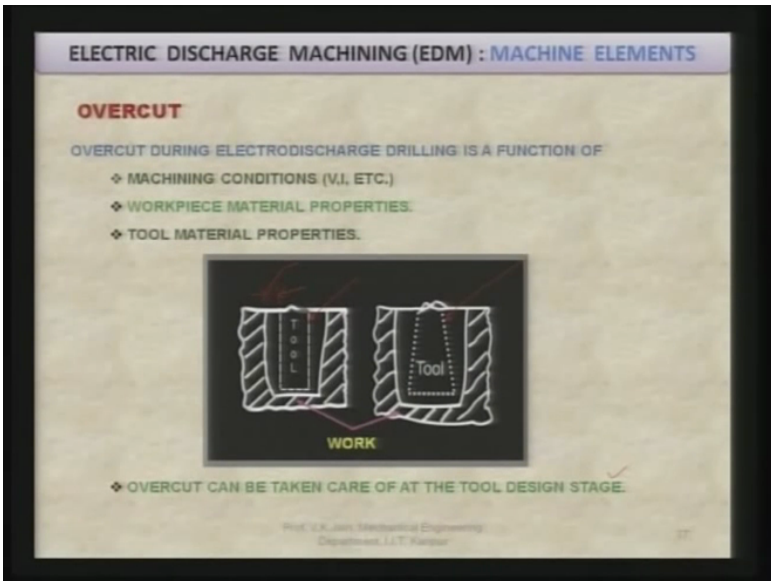

It is important to understand the over cut obtained in EDM because this decides the accuracy with which you are going to make the component or the parts by EDM process. Over cut during electrode discharge drilling is a function of machining conditions those includes voltage, current, pulse on time, duty cycle, workpiece material, type of the dielectric, et cetera. Then it depends upon the workpiece period properties, tool material properties and you can see here clearly shown that the 2 workpieces are shown and in both cases say in this particular case this is the radial over cut as you can see in the diagram I have drawn here this is the radial over cut and double of this will be the diametral overcut.

Now here you can see clearly that the tool is straight sided and you are getting the tapered workpiece but if you make the reverse of this taper on the tool then you will get straight sided hole in the workpiece as you can see here is the reverse tapered tool and the side of the side wall are more of less straight compared to the 1st case, so if you create reverse tapered on the tool you will get more straight sided walls in case of EDM processes. Over cut can be taken care of at the tool design stage, so when you are designing the tool you take on you consider what shape and size of the overcut varies along the axis of the tool then that can be taken care of at the time of design of the tool as I have shown here in the 2nd figure that is on the right side and this way you can design the tools so that you get more accurate shapes or cavity machined by EDM process.

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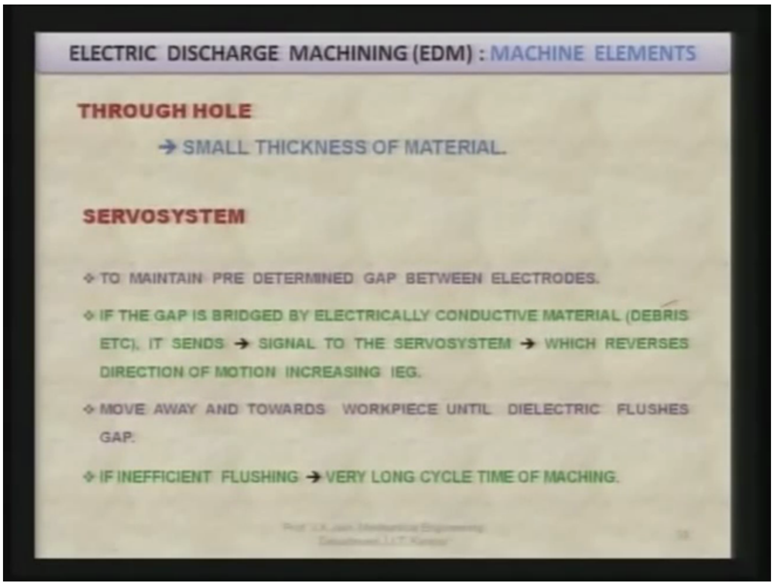

Now you other than the blind cavities you can make the through cavities with the help of EDM process also but very thick workpieces cannot be easily machined by EDM process mainly that flushing or supply of the dielectric in the interelectrode gap is difficult in many situations, so that point we have to keep in mind while selecting this particular process for say deep hole drilling or making the cavities at a reasonably large depth. There is a servo system which is used to maintain the predetermined gap between the electrodes as I mentioned in the earlier class also that when the gap is smaller than the desired one that tool is taken away from the workpiece and when the gap is large compared to the desired one then tool is brought nearer to the workpiece by the servo system and this function is performed quite efficiently by the servo system.

So that you can maintain more or less constant gap during EDM process and this is a requirement during EDM process to get the sparks. If the gap is bridged by electrically conductive material that is the debris, it sends the signal to the servo system which reverses direction of motion increasing the interelectrode gap and flushing comes into picture. The importance of the flushing comes into picture here that debris when they get collected or assembled in the interelectrode then they should be quickly flushed out by the dielectric and for which you may have to supply the dielectric at high pressure.

Move away and towards workpiece until the electric flushes the gap, servo system move the tools either towards the work piece or away from the workpiece depending upon the requirement, so that the gap is cleaned and pressed dielectric comes in the in between the tool and the workpiece that is the interelectrode gap. If inefficient flushing is there then cycle time of machining will keep increasing because a flushing is not proper then then the tool comes nearer to the workpiece then again servo system senses that it is still bridged then it will go up again and then come back and then go up again with without really machining the material from the workpiece and it ultimately increases the machining cycle time, so efficient flushing is very important in case of EDM process.

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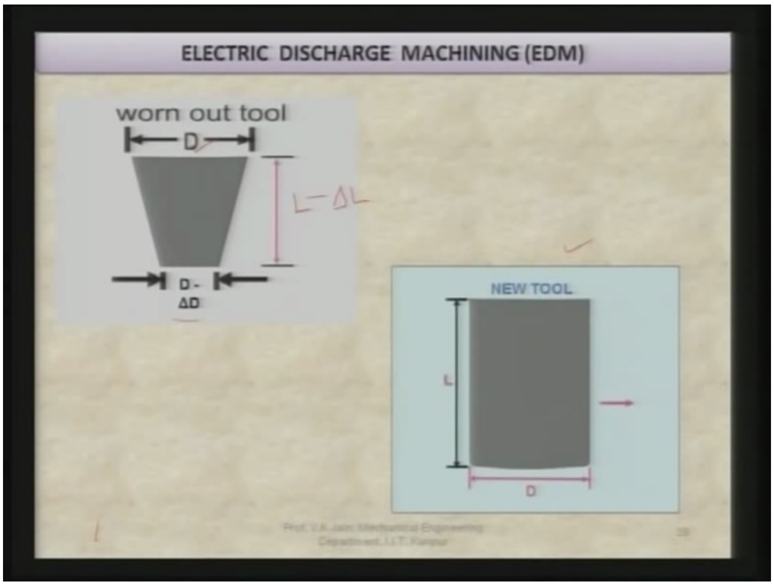

Now as we were talking about the wear of the tool you can see this is the worn out tool, initially the new tool was of this shape and size and when it worn out, its diameter at the bottom has reduced from D to the D minus delta D and length has reduced from L to delta L minus delta L, so you have to make the compensation in the left length direction as well as in the diameter direction both are shown over here considering the 2D tool.

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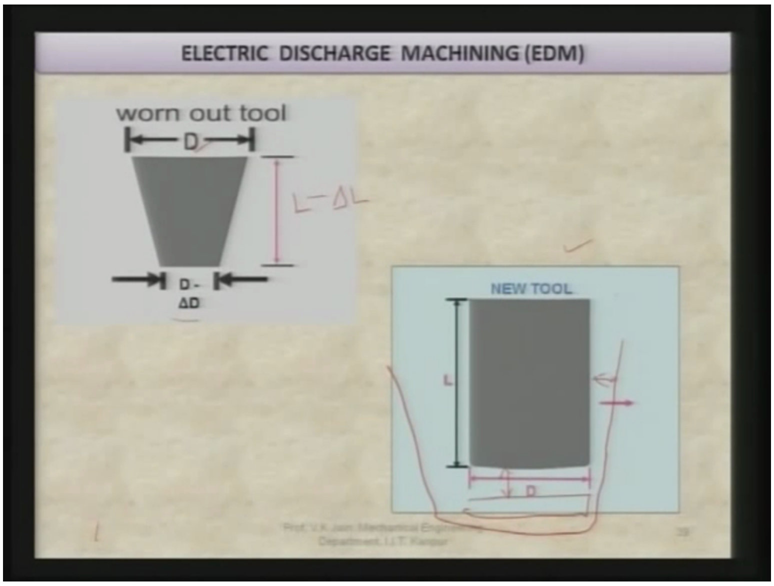

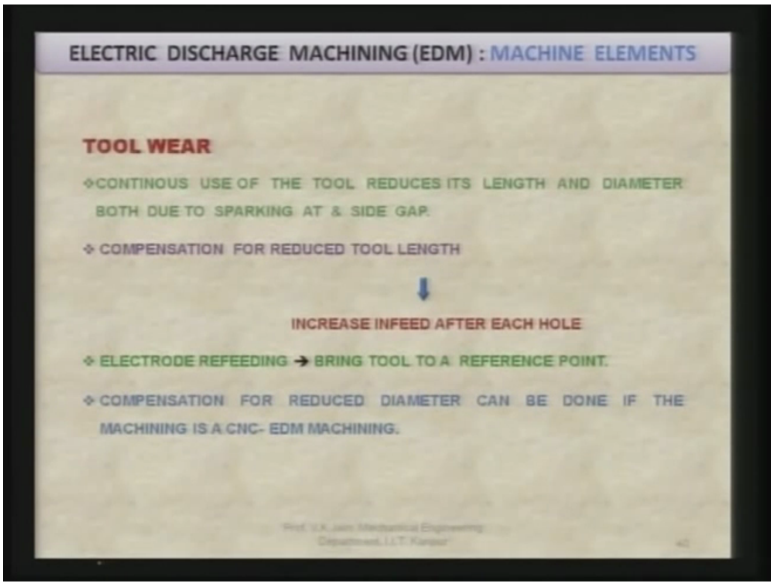

Tool wear, continues use of the tool reduces its length and diameter both due to sparking at the front gap as well as in the side gap which I have shown in the earlier slide as you can see here, here if the workpieces is here then this becomes the front gap and when it is machining the workpiece like this then this becomes the side gap which is varying. So we have to make the compensation for reduced tool length as well as diameter, now for compensating the length you increase the infeed after drilling each hole, so that it reaches to the reference point keeps changing as I will show you here.

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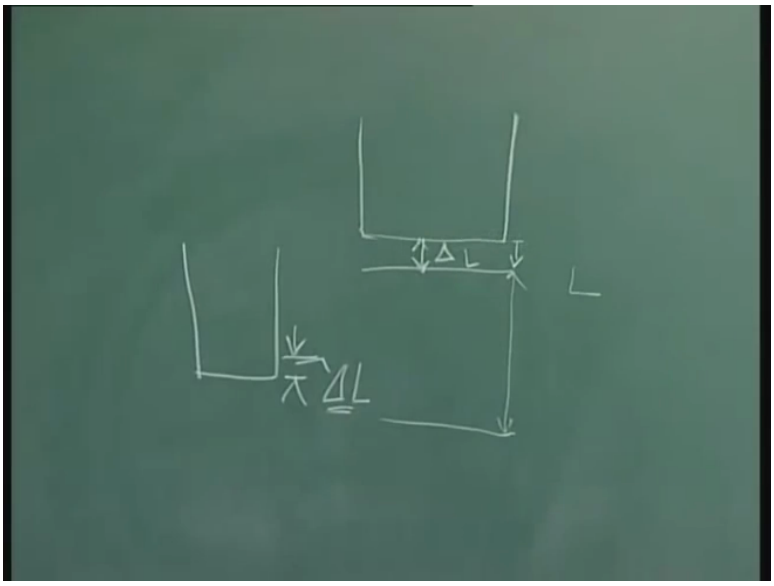

Suppose the tool has worn out by a length equal to delta L and say reference point of the tool in the machine is this, so to compensate this delta L this reference point should be shifted downwards by our length equal to delta L, so when you give the feed equal to L then it will drill the hole equal to L over here so that you will get the correct depth of the hole. Electrode refeeding is to bring a tool to a new reference point that is from here with this reference point and this is equal to delta L which is equal to the worn out length of the tool. Compensation for reduced diameter can be done if the machining is a CNC EDM that is if it is a computer numerical control EDM machine then you can do the compensation for diameter also which require automatic changes in the NC part program to take care of wear of the tool in the diametral direction.

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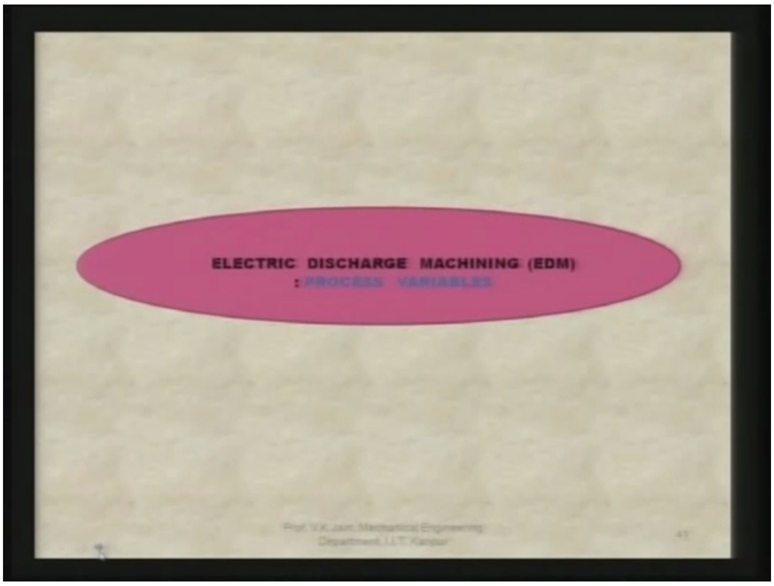

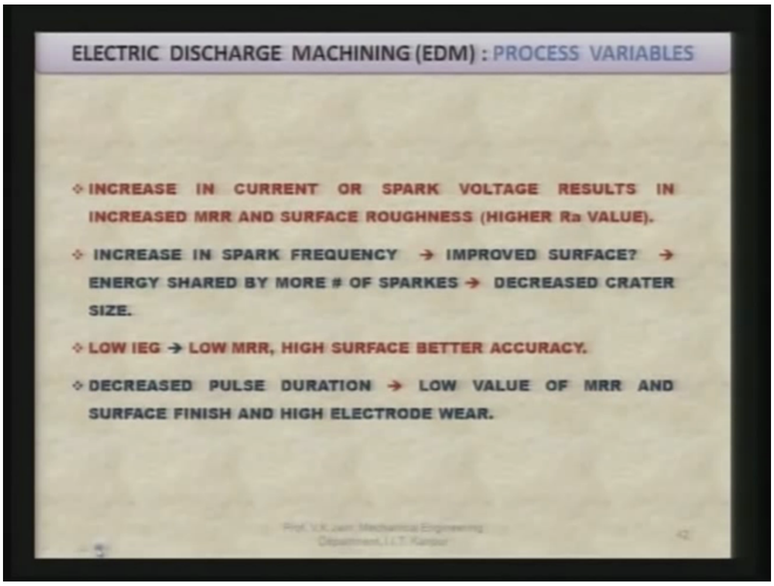

Let us see some of the process variables and their effects, if you increase or increase in current or spark voltage results in increased material removal rate MRR and surface roughness that is you get higher Ra value that is CLA value or you can say rougher surface. Increase in spark frequency you will get improve surface energy shared by more number of sparks hence the decreased crater size. Then the same energy shared by more number of sparks then the energy per spark will reduce and if the energy per sparks reduce then definitely size of the crater that you are forming will reduce that will result into the improved surface finish or lower Ra value.

Low interelectrode gap will give low material removal rate that means lower size of the crater and you will get high surface finish and better accuracy. What happens really, due to the low interelectrode gap the breakdown voltage reduces and due to the reduction in the breakdown voltage the energy per spark also reduces and due to the reduction in the energy per spark, the crater size reduces hence you get better surface finish and better accuracy. Decreased pulse duration leads to the low value of MRR and low value of surface finish and high electrodes wear.

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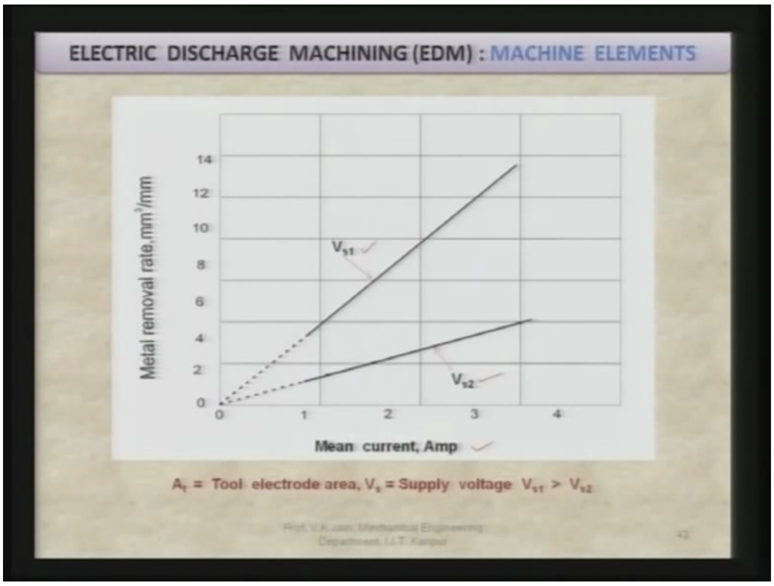

What I mention in the earlier slide is visible is shown over here this particular figure you can see as the current increases the material removal rate is also increasing and V s1 and V s2 are the 2 voltage is and V s1 is larger than the V s2 and since larger at high voltage there is a higher energy per spark because of that higher material removal rate is there but crater size is also higher as a result of that surface finish will be poor and you can clearly see here at low voltage the material removal rate is lower so you will get better surface finish.

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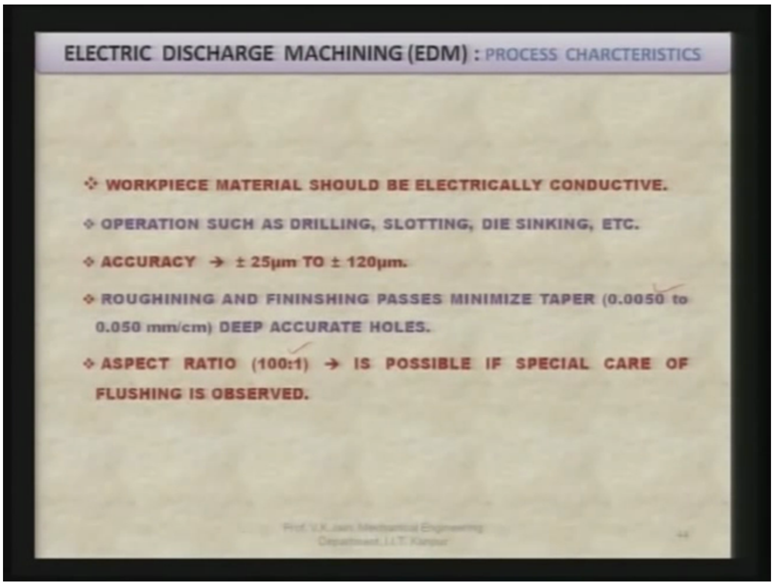

I have already mentioned that workpiece material should be electrically conducted otherwise it cannot be machined by EDM process and operations such as drilling, slotting, die sinking, et cetera can be easily performed using EDM process. The accuracy that you can obtain by this particular process is plus minus 25 micron 2 plus minus 120 micron. Roughing and finishing passes minimise taper and you can make deep accurate holes. The taper can lie somewhere 0.005 to 0.050 millimetre per centimetre.

Aspect ratio that is length to diameter ratio 100, it is possible to achieve by EDM process but in a very special cases that is very special care of flushing this observed because as you go deeper and deeper the flushing becomes more and more difficult and you will require higher and higher pressure of supplying the dielectric and many times you cannot go beyond a certain pressure that is why you cannot achieve high aspect ratio in case of EDM this hundred ratio 1 is in a very special case, normally it is 15 to 20 aspect ratio which you can machine by EDM process.

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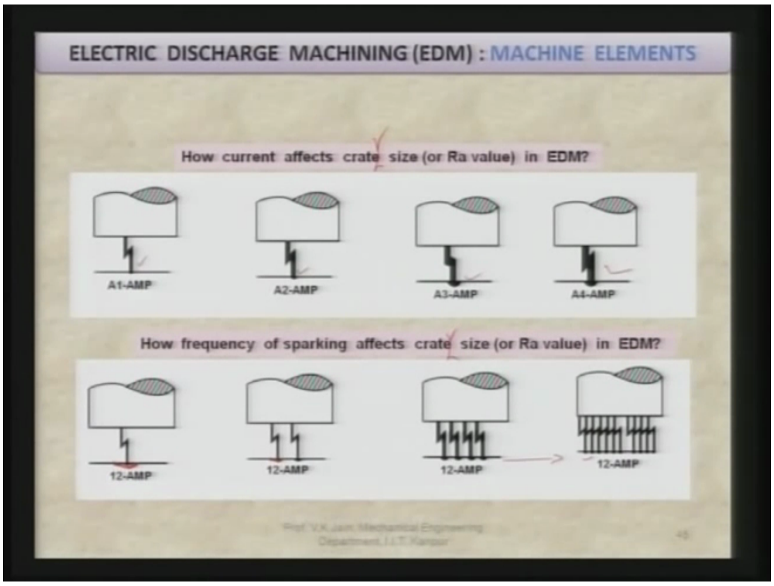

How current affects the crater size crater size and this crater size is going to affect the Ra value also, so let us see how it changes. Now if it is 1 ampere then the energy per spark will be lower compared to 2 ampere and if energy per spark is lower then definitely the crater size is going to be lower, so you can see at 1 ampere crater size is very small, 2 ampere it is slightly larger, 3 ampere is still larger and 4 ampere largest amongst all the 4, so that simply means that larger the current, larger the crater size and if crater size is larger then the surface roughness will be also be larger that means poorer surface finishing.

However, material removal rate will increase as I have shown in the earlier slide. Now another variable is the frequency of sparking and how sparking how frequency of sparking affects the crater size, crater size or Ra value in EDM let us see. Now you can see here the in all the 4 cases the current remains 12 ampere only but in the 1st case the when the current is 12 ampere the crater size is quite large that is not drawn properly it is quite large but as the frequency of sparking increases 2 then the size of the crater is going to reduce.

So as you can see here as the frequency is increasing size of the crater is continues decreasing that simply means that larger the frequency better will be the surface finish and that is why at higher frequency but keeping all are the parameters constant like voltage, current, interelectrode gap and others you will get better surface finish and that is represented over here this should be something like this, it should be slightly lower than that, this will be smaller than this particular one but it will be bigger than this case and this is the lowest size of the crater that you are going to get.

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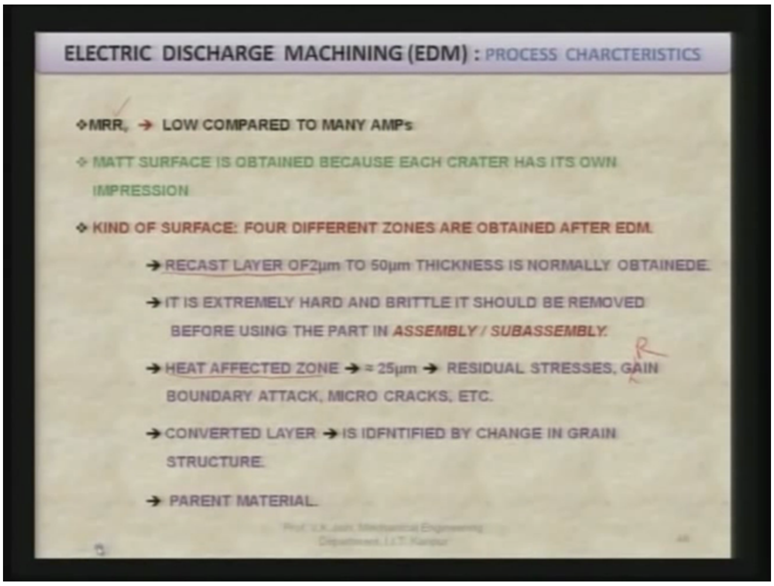

Now in case of EDM process volumetric material removal rate that is MRRv is very small, it is very low say compared to ECM process. Now you get matt surface finish because each crater has its own impression on the machine surface and there are always overlapping craters and because of these overlapping craters you get better surface finish but surface obtained is always having the crater and many a times you need such kind of craters on the machine surface especially when there is the relative motion between the 2 component and you want to retain the lubricant between the tools surfaces, so these craters help in retaining the lubricant, so sometimes they are desirable.

Kind of surface, 4 different zones are obtained after EDM as you can I will show you later in the following slide, first is the recast layer and the size of that or thickness of that recast layer is normally 2 micron to 50 micron and it depends upon machining parameters. Second one it is extremely hard not the second one this recast layer is extremely hard and brittle, it should be removed before using the part in assembly or subassembly because this is very hard and much harder than the parent material, so it has to be removed and for removal of this recast layer one of the common method used is the abrasive flow finishing process. Second zone is the heat affected zone, now this heat affected zone is around 25 micron in size and residual stresses are there in this heat affected zone and grain boundary attack, micro cracks, et cetera are there they affected. Another is the converted later, it is identified by change in grain structure and last layer is the parent material.

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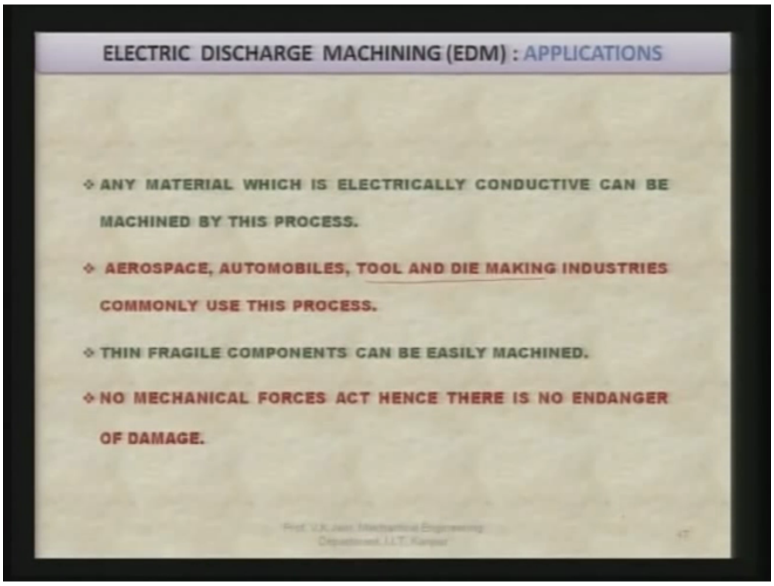

Any material which is electrically conducted can be machined by this process we have already seen that, that forms either anode or cathode. It has many applications it has the application in aerospace industries, auto mobile industries, tool and die making industry. Actually this particular process was initially developed for tool and die making industries later on it found application in various other types of the industries also. Thin fragile component can be easily machined by this particular process, the beauty of this processes that you are not applying any kind of mechanical forces, so the chances of fracture or failure of this fragile components are minimised in case of EDM process. No mechanical forces act hence there is no danger of damage to these fragile components.

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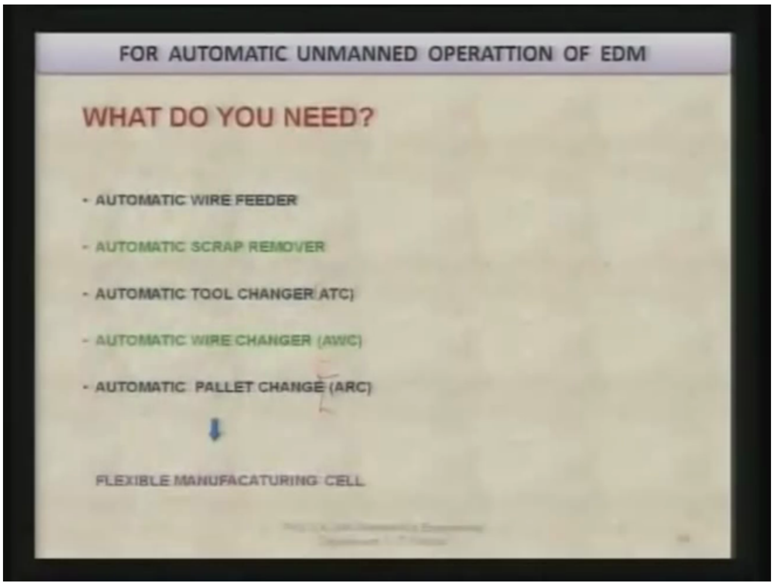

Now another thing is automatic unmanned operation of EDM, why do we need it? You need when you want to use say there is another process called wire EDM process where wire is used as a tool rather than the solid tools that have shown to you in the earlier slides, so the question is in wire EDM process wire breaks, how will you continue with this? And you require operator but nowadays there are the machines which can thread this wire automatically even in the absence of the operator, so you need automatic wire feeder for that purpose.

Automatic scrap remove, whatever is the scrap formed of the debris et cetera or used other materials they should be removed and that can be done automatically. Automatic tool changer that is known as ATC or in case of wire EDM you need automatic wire changing system, so these automatic tool changer change the tool during the operation, they take away the used tool and replaced by the new tool and in that way you can run the machine in the absence of the operator also. Automatic wire changer is their same way as automatic tool changer.

Automatic pallet changer, here pallet means the platform where you are holding the workpiece and when one workpiece is complete and the same machine is running in night hours then you do not have the operator then the machine automatically removes the machined workpiece from the machining area and brings the new workpiece which is to be machined and in loads it there and start the EDM machine automatically and that is how you can run the unmanned operation on the EDM machine and that comes in the category of what is known as flexible manufacturing cell, so flexible manufacturing cell includes such kind of automatic unmanned operations of EDM process.

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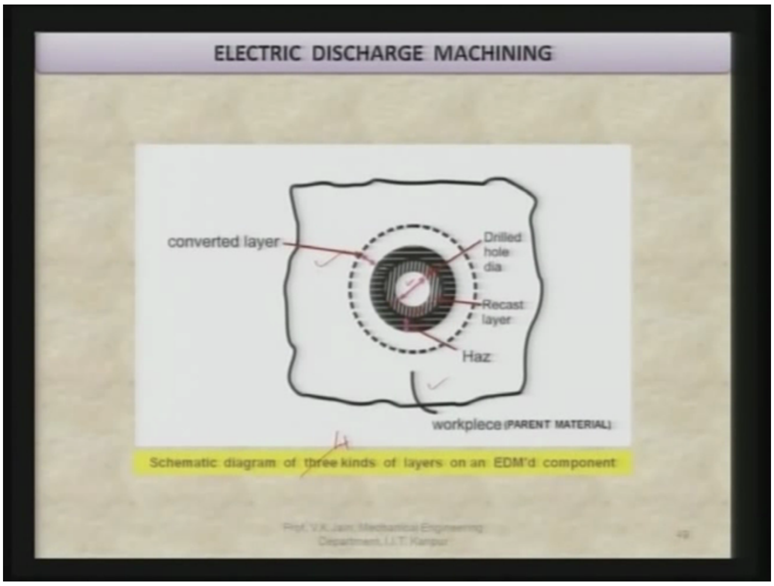

Now the 4 different kinds of layer I mentioned a bit earlier you can see clearly in this particular figure this is the hole that has been drilled using EDM process and this is the thickness or the recast layer just adjacent to the drilled hold and after the recast layer you will find there is the heat affected zone layer which is very small but that is there where microstructure and other properties of the parent material have changed and then you have the converted layer or there where some thermal changes or microstructure changes of the workpiece parent material have been have taken but to a smaller extent and finally you have the parent material that is the workpiece.

Now here you can see this recast layer is there which is to be removed either by AFM process or some the process before really putting this workpiece into the assembly or subassembly whatever it is and once that recast layer is removed then actual dye meter of the workpiece that you are going to get will be this one rather than the drilled hole diameter shown over there, so one has to be careful, really do you want this drilled hole diameter you want to have that one has to see, so it shows a schematic diagram of 4 kinds of 4 kinds of layer on an EDM component including the parent material.

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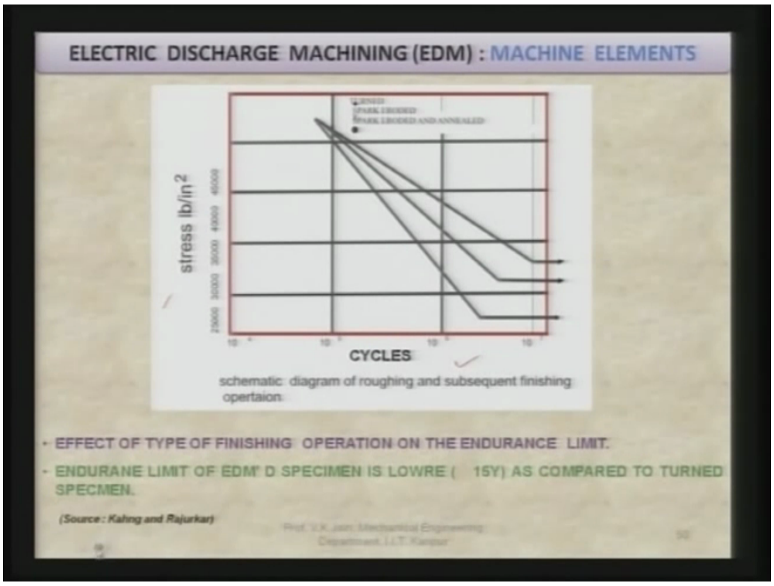

Now it tells you the schematic diagram of roughing and subsequent finishing operation, now here you can see the endurance limit of the EDM workpiece, now these other number of the cycles and here is the stress developed and you can see in this particular note very clearly shown over here but after EDM process it has been found that it is fatigue strength goes down compared to other processes. Endurance limit of EDM D specimen is lower as compared to the turned specimen.

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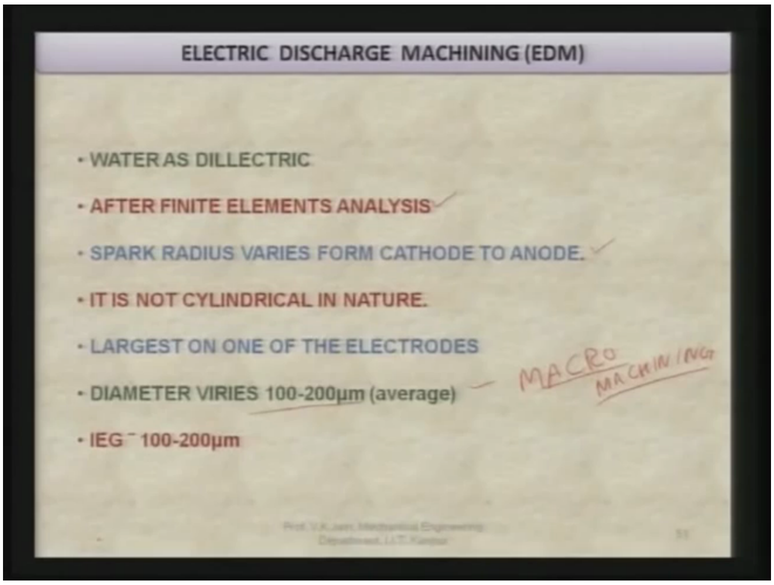

Now as I mentioned earlier at there are various kind of dielectric which are commonly used in the EDM process but recently the trend is to use water also as dielectric as far as possible because it has certain advantages but there are certain disadvantages also, so water as dielectric is also being tried after finite…what we have done, that we have tried to analyse and find out the characteristics of the sparks that takes place during EDM while using water as the dielectric and I will show you some of the interesting results about the sparks form during EDM process and for that particular purpose and we conducted the finite element analysis of the sparking zone.

Here you will find these spark radius varies from cathode to anode and it is not the cylindrical shape of the spark rather a different shape and that shape and size of these spark depends upon the properties of the dielectric, properties of the workpiece material and properties of the tool material. It is not cylindrical in nature. Largest diameter of the plasma column of the sparks is on one of the 2 electrodes is the cathode and anode and diameter varies 100 to 200 micron. Now here I am talking about the macro machining, in case of macro machining the diameter varies from 100 to 200 micron, when I say macro machining that means sparks size is quite large, in case of micro-machining these results are not applicable because their the voltage is very small compared to what we use in case of macro machining. The interelectrode gap in case of macro machining you normally maintained around 100 to 200 micron, so you can see the dimensions of the column, plasma column that is formed over there.

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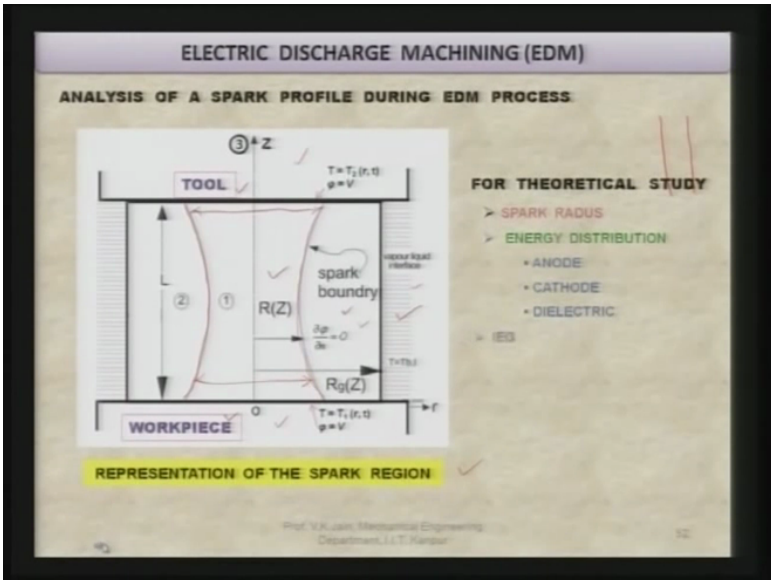

Analysis of a spark profile during EDM process, now representation of a spark region you can clearly see now this is very interesting, here is the tool and here is the workpiece and this tells you really the shape of the spark that you are going to get on in the interelectrode gap between the tool and the workpiece and it is not cylindrical which is normally assumed in case of theological cases, theoretical analysis they assumed that the shape of this plasma channel or spark shape is cylindrical, it is not so you can clearly see. Now here while analysing the help of finite element method various conditions or assumptions were made and various boundary conditions were taken they are available in the research paper but next to the spark or this is the plasma column and next to this plasma column you have the vaporised dielectric and next to the vaporised dielectric here you will find the dielectric in the liquid form.

Now it is interesting once the spark is over or off time is there then what happens this vaporised dielectric you know sudden rise in that pressure is there and that helps in injection of the debris and other reaction products from the interelectrode gap, so this high-pressure or shockwave helps in removal of these debris, et cetera from the interelectrode gap, so this is the diameter that is varying of the plasma channel near the workpiece and this is the one which is near the tool. Now for this purpose for finding out all these shape of the plasma channel, we made certain assumptions of the distribution of the energy, we rather found theoretically also that how much energy or how much heat is (())(42:42) dielectric and based on that this particular profile of the spark has been calculated.

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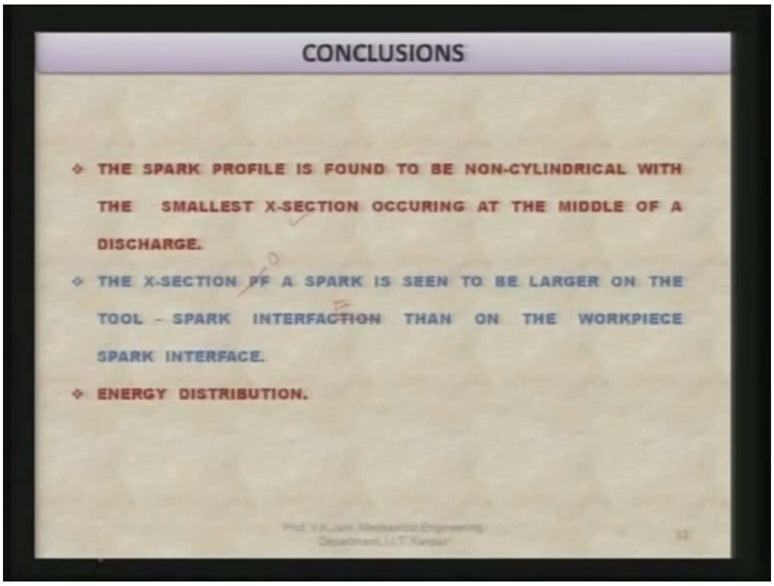

Now based on this there are certain conclusions regarding the profile of the spark during EDM process while using water as the dielectric, these spark profile is found to be non-cylindrical in nature as we have seen in the earlier slide with the smallest cross-section occurring at the middle of a discharge or a middle of a plasma column. The cross-section of a spark this is of a spark is seen to be larger on the tool spark interface then on the workpiece spark interface. Energy distribution was the also calculated and it was found that the energy or the heat conducted to the tool was different from the total amount of heat conducted to the workpiece and it is controlled by the thermal property of the tool material and the workpiece material.

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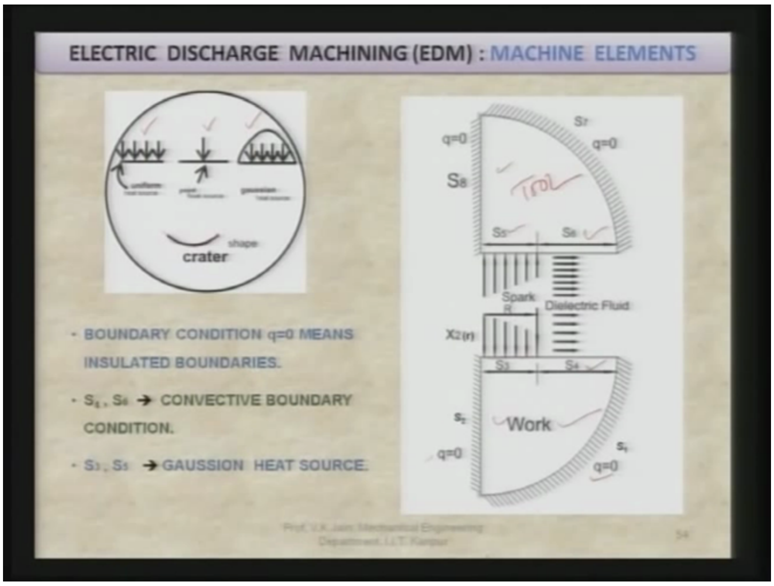

Now I had mentioned that during the finite element analysis you need the energy source and the shape and size of energy source is very important, various researchers have assumed various kind of the heat sources, some of the researchers have taken point heat source, some researchers have taken uniformly distributed heat source. What we have done in our case was the Gaussian heat distribution that means it is varying like this, now the reason for assuming Gaussian heat distribution is very simple because when we see the crater on the workpiece they are form like this and this is just the inverse of the Gaussian heat distribution that is why we presumed that Gaussian heat distribution works during EDM rather than the point heat source or the uniform heat source because it is very close to the crater shape than compared to other 2 heat sources that is why Gaussian heat distribution has been utilised in the finite element analysis.

The distribution rather than the boundary conditions and the domain which was considered during finite element analysis shown over here, you can clearly see this is the workpiece and this is the tool and here is the sparking taking place in the zone S 5 the sparking is taking place, so this S 3 over here and S 5 over here are the zone in which really the spark is taking place and S 6 and S 4, the heat is converted the dielectric and in these areas heat is conducted to the tool as well as to the workpiece, so you can see clearly the boundary conditions q is equal to 0 on S 1, q is equal to 0 on S 2 same way q is equal to 0 on S 8 and q is equal to 0 on S 7 that means they are insulating boundaries for the purpose of finite element analysis and they are far away from that particular area. So you can…I have already mentioned S 3, S 5 are the Gaussian heats sources and S 4 and S 6 are the conviction boundary conditions.

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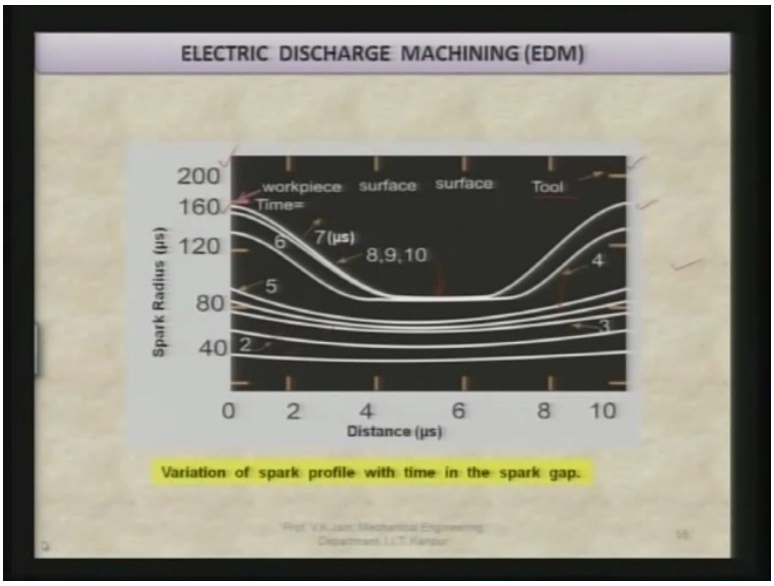

Now during analysis we try to calculate the growth of the spark in the interelectrode gap and this is very interesting result as you can see here is indicate the boundary of the tool, this indicates the boundary of the workpiece and how the spark is changing its shape and size with time you can see here this is the after 1 microsecond, this is at 2 microsecond, this is at 3 microsecond and you can see here after this is for 4, after a certain microsecond that is after 6 or 7 microseconds the spark shape is stabilising and that stabilisation clearly indicate that the spark radius is higher at the tool and comparatively higher at the workpiece tool this is the tool, so higher at the tool and lower at the workpiece and you can see the how the shape of the spark is changing with the time on both sides tool side as well as work piece side and as I have mentioned in the earlier slide that the minimum diameter of the spark is obtained more or less in the middle of the spark, so that assumption that the spark is straight sided cylindrical in shape is not really very correct as we have seen in this particular figure.

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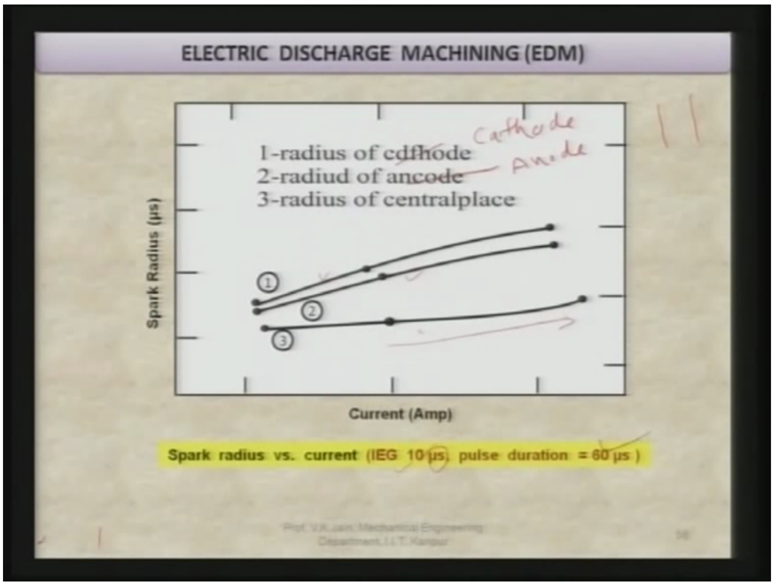

Now here you can see the variation of the spark radius for different currents, now one is the radius of the spark at the cathode to indicate the radius of the spark at the anode and 3 indicates the radius at the central plane, so this is the cathode and this is the anode and it is in the Central plane, so you can clearly see that as current is increasing the radius on all the 3 in all the 3 regions is also increasing. Here interelectrode gap 10 micro this is the this is the time for 10 microsecond and pulse duration was 60 microsecond.

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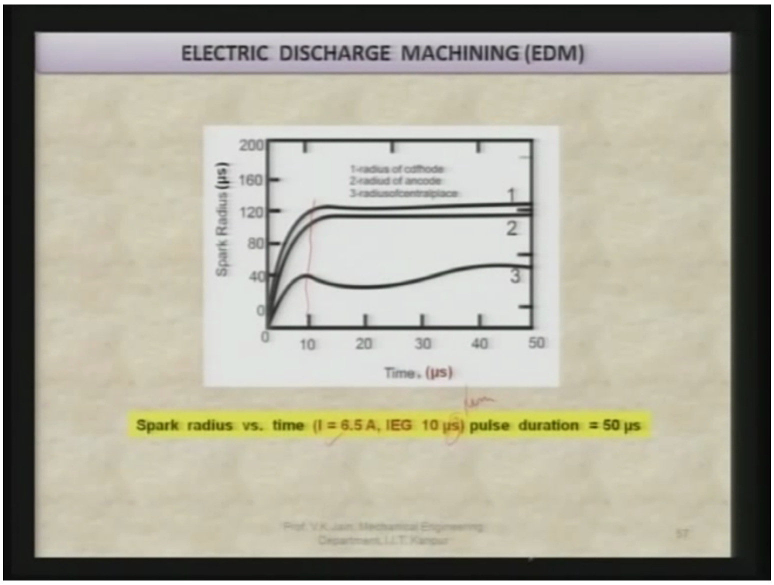

This is the variation of the spark radius with time, you can see here that as I have showed in the earlier 2 slides or 3 slides back that after a certain period of time around 10 microsecond the shape and the size of the spark more or less stabilises, so we studied that one and you can say after about 10 microseconds the shape the radius of these spark at all the 3 locations that is the cathode, anode and central plane are more or less constant, they become more or less constant and for this one current was 6.5 ampere interelectrode gap was 10 micro-meter and pulse duration was 50 microseconds.

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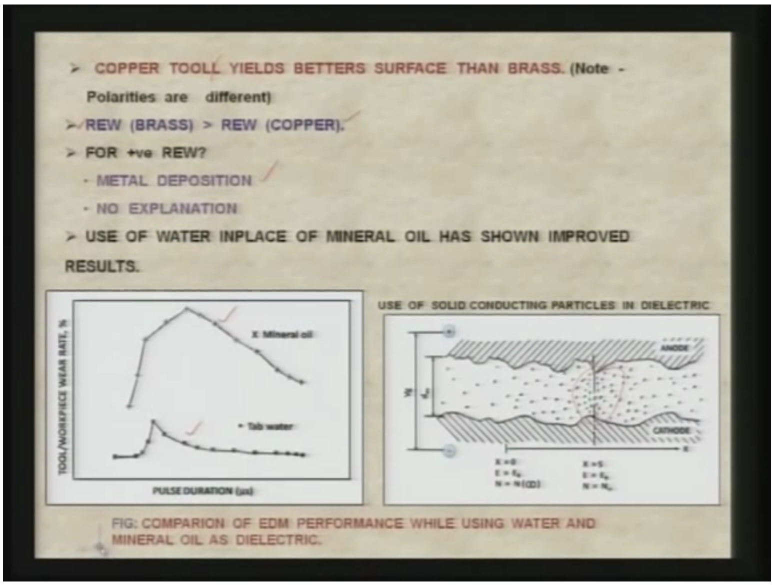

It is also reported that copper tool yields better surface finish than the brass tools that means if copper is used as the tool material the surface finish obtain is better than when the brass is used as the tool material and please note that in both the cases brass and the copper, the polarity used are different, in one case it is the normal polarity while in another case it is the reverse polarity. Relative REW is the relative electrode wear in case of brass is more compared to the relative electrode wear in case of copper tool. For positive…

In some cases positive relative electrode wear is found that means instead of reduction in the mass of the tool it increases and then researchers try to find out why the weight of the tool is increasing rather than decreasing then they found that some metal deposition has taken place on the tool that is why one finds a reverse trend that is the larger the mass of the tool after machining rather than decreasing. However, scientific explanation so far has not been given by the researchers for this particular phenomenon. Now use of water as I mentioned earlier, in place of mineral oil as the dielectric is shown improved results, you can see here it shows that the relative electrode wear in case of mineral oil is higher as compared to relative electrode wear when you are using tap water as the dielectric.

Now lot of research is going on in EDM dielectric also. Earlier industries, practitioner and researchers they were using liquid dielectric but recently research lot of a group of researchers have conducted experiments by mixing some particles in the dielectric, some researchers have mixed the electrically conducting particles say copper or some other material or graphite rather in the dielectric and some researchers have tried to add electrically non-conducting abrasive particles in the dielectric and conducted the experiment and when you are using electrically conducting particles mixed in the dielectric, you find that the sparking they try to concentrate in the area where there is a least resistance between the anode and the cathode as can see here there is the minimum gap.

So least resistance is there but those particles try to concentrate in this region where spark is going to take place and the sparking takes place at lower breakdown voltage compared to the case when there are no such electrically conducting particles and that definitely changes the material removal rate as well as the surface finish that you are going to obtain after EDM process, comparison of EDM performance while using water and mineral oil as dielectric which I have shown over here.

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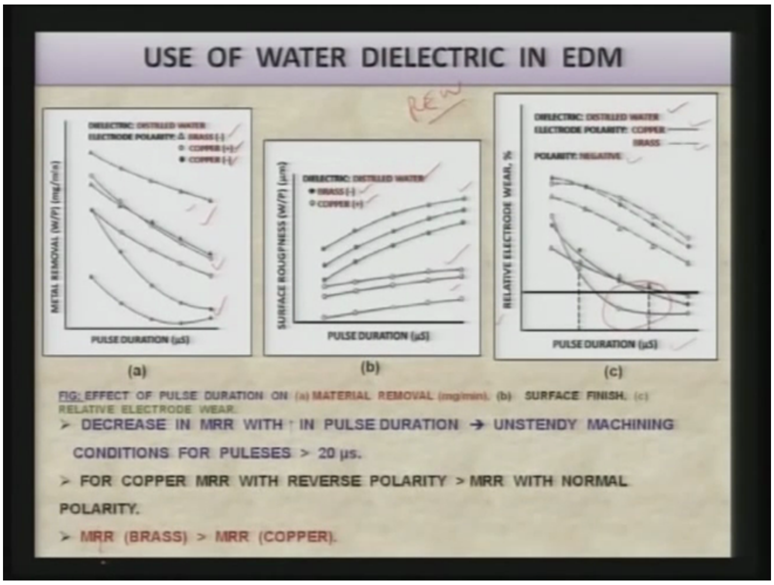

Here if we see use of water as dielectric in EDM there are certain results given over here which clearly indicates one is the brass with electrode polarity that is the tool polarity negative that is the cathode and then copper with normal polarity and then copper sorry copper with reverse polarity and then copper tool with normal polarity and if you see here copper with normal polarity material removal rate is lower compared to the copper with reverse polarity and brass with normal polarity is used but in case of brass as the tool material the material removal rate observed is higher compared to copper with the normal polarity.

Also another thing you can note here is that is the pulse duration is increasing then the material removal rate from the workpiece is decreasing in all the 3 cases. Surface roughness value versus pulse duration and here distilled water again is used as the dielectric, brass with the normal polarity and copper tool with the reverse polarity and you can see with the reverse polarity in this particular case surface roughness is better that means lower surface roughness value or better surface finish is there as compared to the brass and this is very obvious when material removal rate is higher in case of brass as you can see over here in this particular case then larger craters are formed and if larger craters are formed then definitely Ra value is going to be higher as compared to the case when smaller craters are formed that is why you can see clearly that in case of copper the Ra value is smaller that is better surface finish compared to the brass in which case the large crater are formed.

Now relative electrodes wear which we can see here again distilled water as dielectric, copper and brass as the tool material, polarity is negative, now one thing you can see here that relative electrode wear there is REW which I mentioned earlier is the relative electrode wear, now related electrode wear is continuously decreasing with the pulse duration that means as you increase the pulse duration relative electrode wear is going to be down.

Very interesting result is over here that is what I mentioned in the earlier slides also that in certain cases you get negative relative electrode wear that means mass of the tool increases rather than decreasing after EDM process and scientifically researchers are as of now not able to explain it satisfactorily why there is the increase in the mass of the tool rather than decrease of the mass decreasing the mass of the tool. For copper MRR with reverse polarity is greater than MRR with normal polarity that we have seen and definitely we have seen these figures that material removal rate in case of brass is larger or higher as compared to the material removal rate in case of copper.

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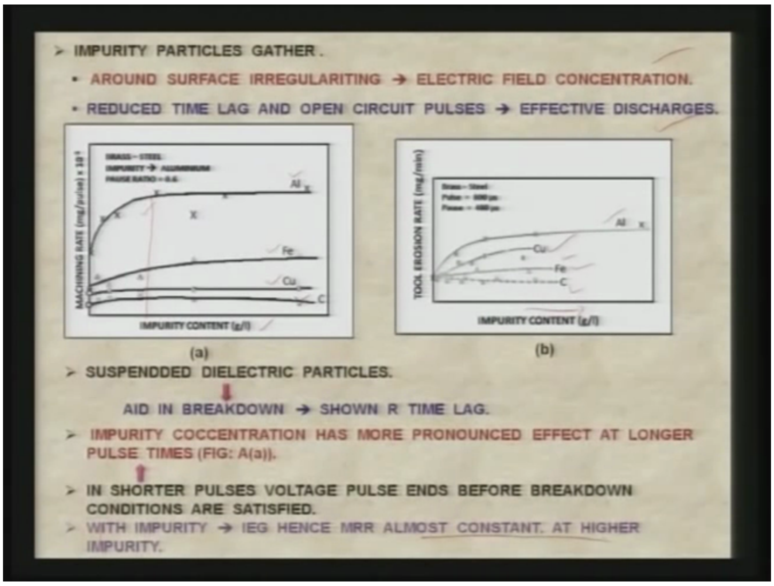

Now impurity particles, what happens? We have seen in the earlier slides couple of slides back that the impurity or the addition of the solid particles gets concentrated in the area where sparking is going to take place. Now what is the effect of this addition of the impurity particles in the dielectric, around surface irregularities these electric field concentration is there where these particle gets concentrated and reduced time lag and open circuit pulses that are effective discharges are there.

So you can see with the impurity content as the impurity content is increasing machining rate is increasing up to a certain concentration as you can see here up to this concentration the material removal rate in terms of milligram per pulse has increased. In case of aluminium slight increases is there in case of iron and insufficient or insignificant effect is there in case of copper and graphite.

You can also see here effect of impurity content on the tool erosion rate, now in case of tool erosion while machining aluminium there is significant effect on the tool erosion rate in case of machining aluminium as well as copper and to some extent on the iron also but in case of graphite it is hardly any effect rather it shows to be little reverse effect on the tool erosion rate while varying the impurity contained in terms of gram per litre. So what happens, suspended particles are there in the dielectric that aid in breakdown shown time lag, impurity concentration has more pronounced effect at longer pulse duration. In shorter pulse duration voltage pulse ends before breakdown conditions are satisfied. With impurities interelectrode gap hence MRR almost constant at higher impurities as we can see clearly over here also you know both the figures you can see this phenomenon.

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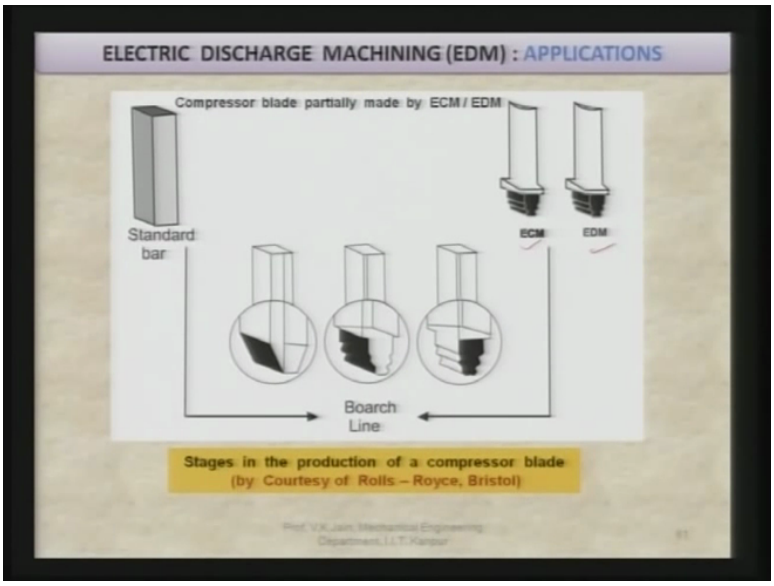

Now there are various application of EDM some of the applications I am going to show here but as I have mentioned in the beginning in the last class that EDM is the most commonly used unconventional or advanced machining process in today's industries an R&D houses as well. Now here I have tried to show that the turbine blades, they can be made certain part of the turbine blades can be made either by ECM process or by EDM process. However, there are certain problems with the use of the EDM process or turbine blades because EDM is thermal process and what so whatever optimum parameter is used, thermal cracks may be in the form of micro-cracks are going to developed over there and so the life of the turbine blades may reduce as compared to the turbine blades are made by ECM process. However, here both the processes are recommended for machining of turbine blades as you can see and after a certain processing you can use broaching also for making the turbine blades other than the EDM after EDM process sorry.

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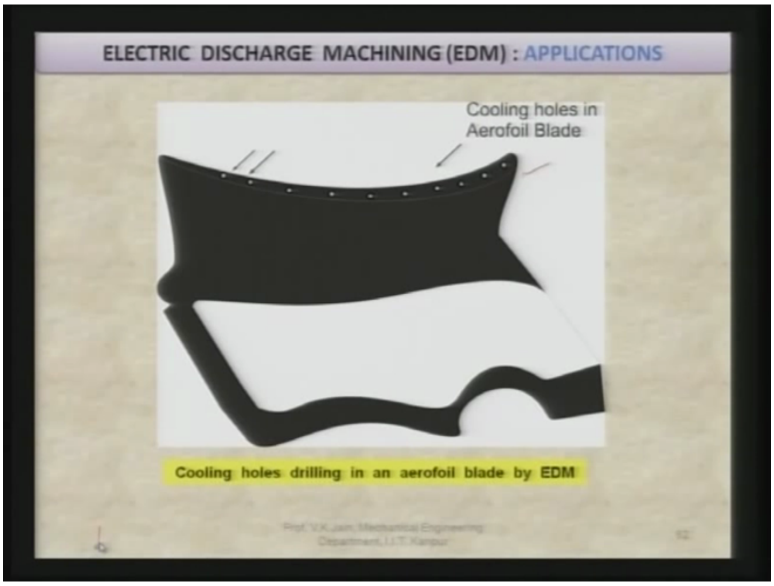

Now for making the cooling holes in aerofoil blades, this process is quite commonly used. Now cooling holes size is quite small may be 1 millimetre or less than 1 millimetre diameter and their depth is not very large in certain cases may be 15 - 20 millimetres, in those cases EDM process is quite useful but the drawback with EDM process is that it is comparatively slower compared to other processes. So you can see here these are the holes, now hundreds of such holes are needed in a particular blade, so what people have done they have made the tool, multiple tools in the single piece and many holes are drilled at the same time that is why the productivity goes up and the total time required for drilling these holes is lower and people have used these electrodes for drilling the holes not vertically even not only vertically even at an angle and they have performed quite well.

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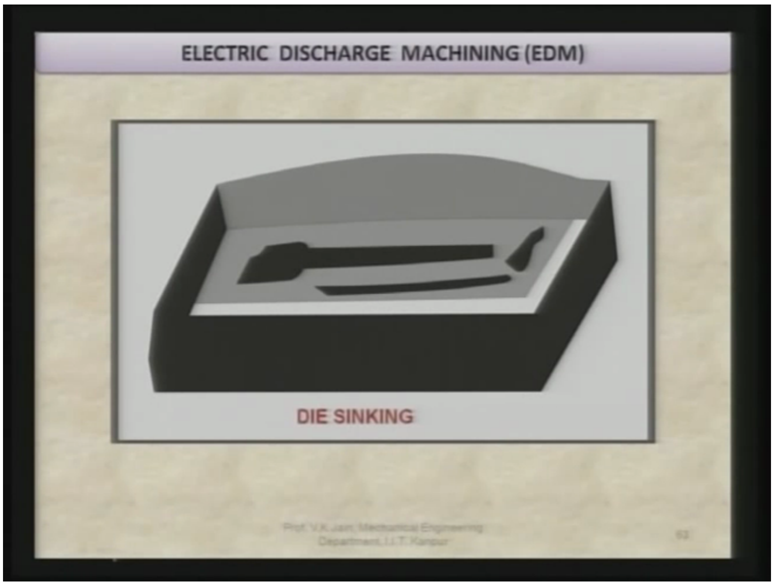

This process as I mentioned earlier was basically initially developed for syncing operation, die syncing operation and you can see here this is the dye figure which is shown over here and you can make such kind of dies and this comes under the blind cavities and different complex shapes of the dies can be easily made but the basic requirement is that you should be able to make the tool of reverse shape and size of the dye and you should take due consideration of designing the tool for dye making so that you can take care of wear of the tool during EDM process. Taper that you are going to get in the dye that should be taken care of at the design stage itself otherwise you will not get accurate dye (())(64:03).

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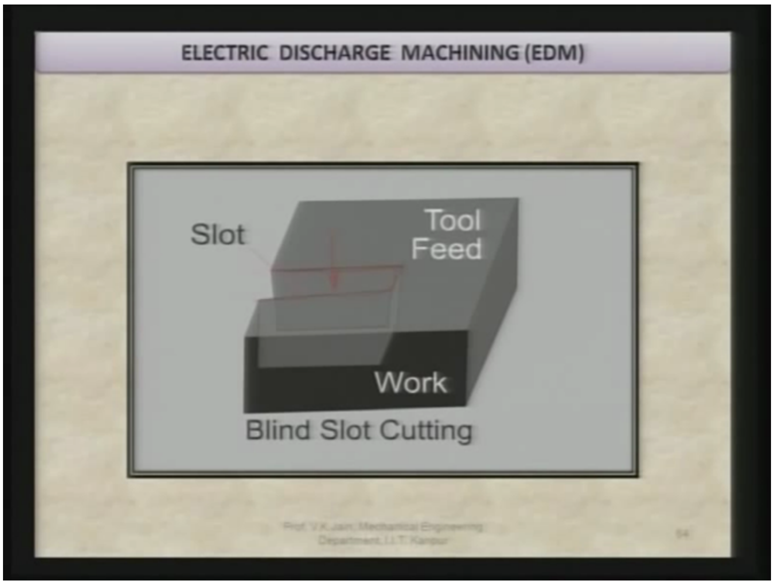

Then you can make the slot also 3D slots also can be made at this particular EDM process, you sink the or move the tool in this particular direction so that you can get this slot made on the workpiece, so it is as good as making the dye the slot is also easily made over there.

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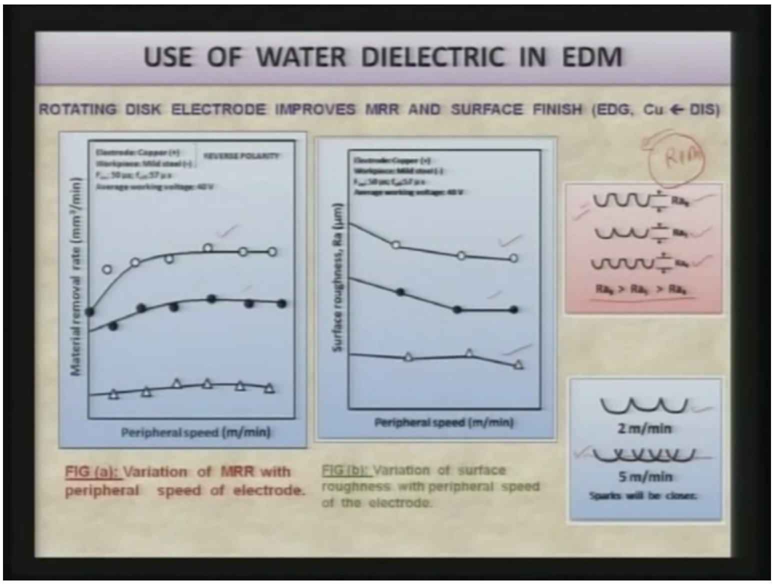

Now there is another process that is the rotating this electrodes, now flushing of the dielectric is a problem especially while you are machining deep, so what some researchers have done that they took the disk type of the electrodes and this disc was rotating and once the disk is rotating then it helps in flushing the dielectric very efficiently and you can machine much deeper in case of disk type of electrode rather than simple solid electrode, so you can see clearly hear the variation of MRR with peripheral speed of the electrodes, this electrodes may be rotating at a particular RPM revolutions per minute and you can see here that as you see here this is peripheral speed is increasing, the material removal rate is also increasing and it is at different current.

Again as the peripheral speed increases surface roughness value is improving at certain current values in this particular case not much effect is there. Variation of surface roughness with peripheral speed to the electrode you can see clearly. Now this is important because as I mentioned many times in these 2 lectures that material is removed by the formation of the crater, now you can see here that when craters are formed at different locations they may be deep or they may be shallow and depending upon the depth of the crater formed you will have different Ra value.

Now in this case Ra value in this case is larger than this and this case it is the lowest of all the 3 that is what shown over here and these are not the single craters at a particular location, most of the time these craters overlaps with each other and you get a much lower Ra value than what you are going to get by the single crater, so the calculation have to be made very carefully in theoretical analysis of surface roughness value obtained in EDM process especially because the craters are overlapping with each other and shown over here, so in this particular case the Ra value will be calculating from this other than from this, so this has to be taken care of and it also depends upon what is he feeds rate of the workpiece that will also decide how much overlap you are going to get on the workpiece and if feed rate is low you will get the deeper crater formation and if fetid is high then you will get the shallow crater formation and overlapping may be there which will further reduce the surface of this value in case of EDM process.

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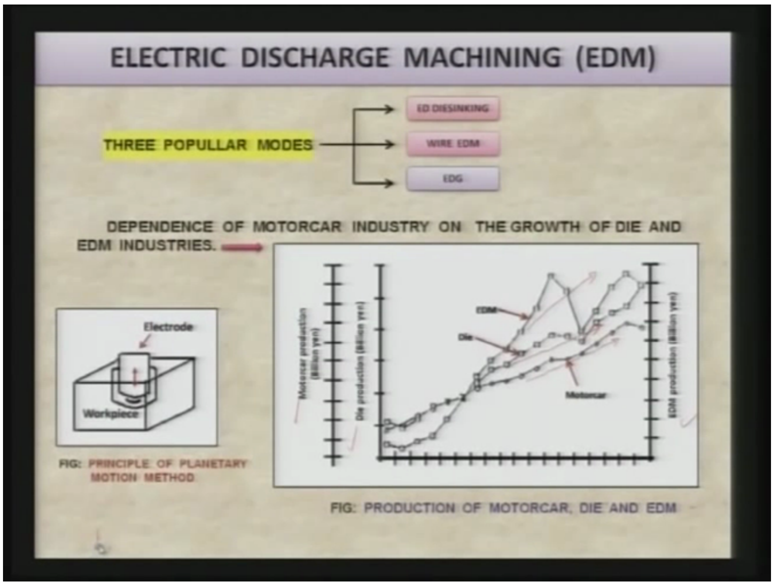

Now this is the slide very interesting slide which I should have shown you in the beginning itself, you can see here production of motor car die and EDM process. EDM as I mentioned, EDM process is very commonly used the purpose of die syncing or in aerospace industries or auto mobile industries or other industries as well. Now one thing is that the dependence of motorcar industry on the growth of die and EDM industries because EDM is very commonly used for die making.

So you can see here that as the here is the motor car production and die production and here is the EDM machine production and you can clearly…this is for EDM as your motorcar industry is progressing the die industries also progressing and with the progress of the motorcar and die industries there is the progress in the EDM production also and you can see that large number of EDM machines are produced in Japan and other countries and their sales keeps on increasing as the order mobile industries are progressing, so this clearly indicates that dependence of these kinds of industries on the development in the EDM machine or EDM technology also. Now here is the planetary motion method which will discuss later on. Thank you very much.