Manufacturing of turbines (gas, steam, hydro and wind)

Dr. Sunny Zafar

School of Mechanical and Materials Engineering

Indian Institute of Technology Mandi

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Lecture 12

Welcome to this course on manufacturing for turbines. In this lesson 12 of this course, we will see further manufacturing processes for gas turbine blades. So in today's lesson, we will see the details of manufacturing of gas turbine by looking at the machining process that is the electro discharge machining. We will understand the basics of EDM process by looking at the circuit on which the EDM work, this is the relaxation circuit, different components of EDM, electric discharge, machining spark description, process characteristics, dielectrics, capabilities of the process, limitations, layer formation and surface characteristics. So EDM process also known as electro discharge machining process is a process which was invented during World War I and II. So this process was developed with the invention of relaxation circuit also known as the RC circuit.

In this process, we have a servo controller which maintains a gap between tool and workpiece and it helps to reduce the arcing. So the servo control also maintains the gap by gradually moving the tool towards the workpiece because as the machining continues, the gap between the tool and workpiece will increase and with the help of this servo control, we control the gap to a specific value. The process is nowadays refined by using several pulsed generators, planetary and orbital motion techniques and of course the computer, numerically controlled and adaptive control systems have refined the process to a very large extent. So we will see the details of the relaxation circuit which was invented by these two scientists.

So the relaxation circuit is basically a nonlinear electronic oscillation circuit which produces a non-sinusoidal repetitive output signal which can take shape of a triangular wave or a square wave. So, if we look at this diagram of the relaxation circuit, so there are different parts in this diagram. So, firstly there is a source of potential difference which is denoted by V0 or Vo, then we have a variable resistance Rc, then we have a capacitor which will store the charge at a voltage Vc. and then there are two currents id and ic one is the open current and Id is the discharge current. So, in the relaxation circuit what happens that as the voltage is supplied the presence of this capacitor basically it stores the charge and upon reaching the peak value it suddenly discharges its charged value which results in formation of several sparks.

So here we can see how the RC circuit is now utilized in electric discharge machining. Here also we have the voltage source V0, the variable resistance RC, then we have the voltage supplied by the capacitor C which is denoted by Vc. and then we have the current going through the capacitor and the discharge current Id. Now, here what changes is that instead of this diode we have this tool and the workpiece. So upon reaching the peak value in VC, so we can see there is a sudden discharge now.

And this type of waveforms are possible with the relaxation circuit in the electric discharge machining. And what happens during the sudden discharge? So several sparks are generated in this tool workpiece gap. And these sparks basically are micro plasmas which are having very high temperature and once these sparks they come in contact with the workpiece, so they consequently remove material. So, if we understand the electric discharge machining process using this pulse current terrain which is generated using a controlled pulse generator. So, there are various aspects to this pulse current terrain.

So, here we have seen that we have a square type of a waveform for current where we have the different parts. For example, this is the region in which the current is supplied and it is known as the on time. Then at other duration that is the adjacent duration, the current is switched off. So, this is known as the off time. Subsequently, we can see that one cycle of this charge and discharge is completed with one on and one off time.

So, this complete up to here is basically one cycle. And then we can say that this value of current is known as the peak current value and this dotted line, this basically shows the average current value. So, by basically changing the on and off time duration or changing the peak current value or by playing around with these parameters, we can change the characteristics, machining characteristics of the electro discharge machining process. Similarly, if you look at the variation of voltage with time using a relaxation circuit generator, so here also we can see that there are different aspects to this plot which include the charging time. Then we have basically the short time just before this.

In fact, this is slightly we can say that this is just before this recharging and then there is a short duration where the discharge happens. This is basically the discharge time. And here also one cycle is basically the complete charge and discharge cycle. So this is how the voltage keeps on varying using the relaxation circuit in electric discharge machining. So now we look at the different components in electric discharge machining.

So in the electric discharge machining, so because of the relaxation circuit, there are several sparks which are produced between the tool workpiece gap and the sparks basically are the microplasmas which interact with the workpiece and because of which material is subsequently removed. So, in the electric discharge machining, we have the plasma phase which is generated. This plasma phase is generated between the tool which is a conductive tool and the workpiece. So, in between to control the discharge characteristics or the plasma characteristics, so generally we introduce a dielectric fluid. We will understand more details about the dielectric fluid in next few slides.

So, before we go into other details of the process, we will try to understand what is basically the setup used for electric discharge machining. So, the setup of electric discharge machining, it consists of a DC pulse generator, where we can say we have plus and minus and then we have a tank, so in the tank we have this fixture, then on the fixture we have the work piece which is placed. So this is the workpiece.

Above the workpiece, we have the tool. This tool is held inside a tool holder and this tool also needs a connection for bringing in the dielectric and we have this servo control servo controlled feed which is there, which is controlling the z axis movement of this tool and tool holder, so this is the tool above is the tool holder and then this dielectric is completely filling in this tank. And here to recirculate the dielectric we have the arrangement of a pump and filter. This is the filter. This is the pump. So the role of the filter and pump is basically to help the dielectric to keep on recirculating.

And the role of pump is basically to filter out the debris which is generated because as several sparks are produced here in between the tool workpiece gap, these sparks, they will erode material and material will be melted. Some material will be evaporated. That is how material will be removed in electric discharge machining. And the molten material will be suddenly quenched and solidified because of which machining debris will be produced. And this debris is subsequently separated from the dielectric fluid which is present in this tank.

We can see the dielectric fluid is always there to submerge the tool and workpiece. And the servo control feed, it will ensure that the constant gap between the tool and workpiece is maintained. Now, the sparks will be only generated once we have the connection of the DC pulse generator. So, in this regard, what is there? So, in fact, I can say this that the positive side is connected to the workpiece and the negative terminal of the EDC supply is connected to the tool. So, because of that the sparks are produced, sparks are nothing but these are the visible routes through which the electrons are flowing from the negative terminal or the cathode to the anode.

And the electrons as they are negatively charged, so they flow from the negative terminal towards the positive terminal, they were producing sparks in the inter electrode gap. So this is a very basic schematic on which the electric discharge machining process works. And in this regard of the course, we know the electric discharge machining or the other machining processes are basically used to generate the film cooling holes in the gas turbine blade as we have discussed. So in the gas turbine blade, So we want to generate this film cooling holes. So film cooling holes are generated using this electric discharge machining in the gas turbine blades.

So we can understand the mechanism of material removal in electric discharge machining by following the figure as shown here. So the complete material removal it takes place between this gap between the tool and workpiece where of course as the discharge of the plasma starts so a plasma channel is developed between the tool and the workpiece. In the plasma channel so there is again the various charge carriers that is the ions and electrons they get separated and based on their respective charge they get attracted to the oppositely charged regions of the arrangement. So, electrons as they are more mobile because of their less mass so they travel quickly from the negative terminal towards the positive terminal and by doing so they basically carry high kinetic energy and upon impacting the workpiece of course the plasma also has high temperature. The material gets removed and removing material also gets solidified as it comes in contact by the surrounding dielectric fluid and some of this re-solidified material is also suspended in the dielectric and some of the material is solidified on the surface of the workpiece in form of the recast layer.

We will see some more details about the recast layer later on. And other thing is that during this process of plasma discharge what happens that the surrounding dielectric fluid also gets evaporated because of which a bubble is formed in this regard and this vapor bubble as the size keeps on growing it also collapses which helps to remove the machining debris from the machining zone. So step by step these things happen in the electric discharge machining process. wherein as the charge peaks, once the charge peaks and discharge starts, so between the tool and the workpiece, so I can say this is the tool and here is the workpiece. So, the first step is the breakdown of the dielectric fluid, so dielectric fluid it breaks So during the dielectric fluid breakdown, the discharge column is established between the tool and workpiece, which basically leads to melting and evaporation.

And because of the surrounding dielectric fluid also coming in contact with this discharge column of the plasma, a bubble is formed. And this bubble size keeps on increasing, or we can say the expansion of the bubble, it takes place. and then as the bubble size increases to a critical value the bubble collapses and because of the collapsing bubble the debris is also removed from the machine surface and then this dielectric is subsequently brought into the pump for recirculation wherein the filter present in the pump system removes the debris and again the setup is ready for the next discharge. Now in the electric discharge machining setup these discharges they happen several discharges take place in a short period of time because of which the material removes very quickly and this presence of the relaxation circuit basically helps to provide lot of high number of discharges in a short period of time because of which material removal rate is much faster. So we can see that the EDM process, it revolves around development of a potential difference between the tool and workpiece.

The electric field is established, so free electrons are available. So once the discharge starts, cold emission of electrons is happening. So collision of electrons takes place with the dielectric molecules upon which the ionization of the dielectric takes place, more electrons and ions are generated. So, plasma channel is formed and there is an avalanche motion which creates the spark. So, high energy electrons and ions they strike the workpiece and subsequently this leads to melting and vaporization of the workpiece.

And because of the collapsing bubble of the dielectric fluid a shock wave is generated which also further helps in removal of material. So we can also look at the electric discharge machining process by looking at the role of various process parameters on the material removal rate. So material removal rate or the MRR is basically the index of productivity. That is how fast a machining process is removing material. generally it is desired in machining processes.

So, this should be as high as possible. This is index of productivity. So, if we see that with reducing the resistance, so the MRR is increasing because as we reduce the resistance, the electron or the current flow increases because of which the MRR will increase. Similarly, if we keep on increasing the main current, again more number of electrons are available and material removal rate increases. Material removal rate also increases with increasing potential difference where V3 is greater than V2, which is greater than V1.

Also with capacitance, as the capacitance value increases, so the capacitor which is present in the relaxation circuit. It can store more charge because of which the material removal rate can increase. And then we have the inter electrode gap. So, IEG here stands for inter electrode gap. So, IEG is again useful only at an optimum gap.

If the gap is too high, again the electrons in the plasma channel may not have sufficient energy to remove the material upon striking the workpiece. And of course, if this gap is again too less, so in that case also the electrons may not have sufficient time to gain sufficient momentum and energy to remove material from the workpiece. So IEG always has an optimum value and this optimum value is different at every process parameter, at every tool and workpiece combination. So we can summarize the various process characteristics of EDM. So this process is capable to machine any electrically conductive material.

So our nickel based super alloys, which are used to make the gas turbine blades, they are electrically conductive. So material removal, it may depend on thermal properties of the workpiece rather than its hardness and strength or toughness. So we know nickel based superalloys are known to retain their hardness and toughness and other mechanical properties even at elevated temperatures. But nevertheless the process capability of EDM is sufficient to create the film cooling holes in the gas turbine blade. The EDM also requires a physical tool which generally makes its replica print on the workpiece.

So whatever is the form of the tool, the similar type of the replica is generated by removing material and tool should be electrically conductive and it may be a soft material. The heat affected zone in EDM is although limited to a short distance of two to four microns below the spark crater. And sometimes in the EDM, what happens because of the rapid cooling of the molten surface of the workpiece, there is surface hardening because of the quenching effect of the surrounding dielectric fluid. And this quenching effect may sometimes create some pores, voids or micro cracks adjacent to the machined layer. So, now we understand the characteristics of the EDM tool or the tool which is used in the electric discharge machining.

So, the tool which is used in electric discharge machining it has to have certain characteristics which include high electrical conductivity. So, high electrical conductivity in the tool is needed for easily emitting the cold electrons while it is cold and there must also be less bulk heating in the tool. The thermal conductivity of the tool should also be high so that it can quickly dissipate heat without local rising temperature and this will ultimately lead to less tool wear. The tool should have high density because for the same heat load and same tool wear by weight there will be less volume removed therefore there will be less loss of dimensional accuracy and the tool should also have high melting point because high melting point will lead to less tool wear due to less tool melting for the same heat load lastly the tool should be cheap and easily available and should be easily manufacturable in various shapes as required for the workpiece. So, in the next slide the table it basically shows the different popular electrode materials or electrode is also sometimes known as the tool in the electric discharge machining.

So, graphite, copper, copper mixed with tungsten, steel and brass are some of the popular electrode materials or tool materials used in electric discharge machining. And for nickel based superalloys as we can see the various tools and their respective polarities are shown as indicated in the table. So, role of polarity is also important because in some cases where very thin sections may need to be machined. So their reverse polarity may also be used. However, using of reverse polarity causes excessive tool wear.

So now we will also understand the various functions of dielectric fluid. So dielectric fluid, they play a very important role in electric discharge machining. So dielectric fluid, it helps to remove the eroded particles from the machining gap. As we can see that there is a vapor bubble which is forming because of the surrounding dielectric with the spark. So, upon collapsing of this bubble, the dielectric fluid helps to remove the debris.

Secondly, the dielectric fluid also provides insulation between the electrode and the workpiece. And lastly, the important function of dielectric is to cool the section which is heated by the discharge effect. So, the adequate characteristics or requirements for any fluid to act as dielectric in EDM are like it should have adequate viscosity, it should have high flash point that is it should not easily catch fire, it should have good oxidation stability, should have minimum odour. It should be available at low cost with good electric discharge efficiency. Commonly used materials or fluids as dielectrics in EDM include kerosene with certain additives to prevent gas bubbles and deep odouring, silicon waste fluids which are mixture of petroleum oils and they are known to give excellent results in electric discharge machining.

Other dielectrics include aqueous solutions of ethyl glycol, water in emulsions and distilled water. And there is another important role of removal of the debris as mentioned previously. So, this is known as flushing. And this the dielectric fluid plays a major role by maintaining a stable machining gap and arc for achievement of close tolerance and high surface quality, because without this flushing action, so there can be decreased electrode life and increased production time. So, in this table, we can see the various other oils which are used as dielectrics with their properties as highlighted in this table.

So we can summarize the EDM process now. So the process has several capabilities among which some of the notable capabilities include that it is able to machine, all the electrically conductive materials irrespective of their strength and hardness and tool and workpiece are free from cutting force. This is important especially for the gas turbine blades, as these are hollow blades and any type of external force after the blades are formed or cast may distort the aerofoil shape. So tooling is also available from formable materials like steel brass graphite etc and the process is able to provide good surface finish accuracy and repeatable and almost there are no burrs produced with minimal thermal effects on tool or workpiece. The process also has some of the limitations which need to be taken care of by various efforts of optimizing the process parameters or some modification in the process. So some of the limitations include there may be low material removal rates especially with difficult to cut materials and hard materials.

There may be presence of recast layer and micro cracks which are inherent features of EDM. which sometimes render poor surface quality. So, EDM process is not suitable for non-conductors and rapid electrode wear may take place, especially once the reverse polarity is being used and surfaces produced by EDM may have a matte surface finish because of the rough surface as we will just see which may need further processing like polishing etcetera to attain a glossy finish. So the recast layer is basically one of the important limitation of EDM and this is generally formed due to rapid solidification of the melted workpiece.

So this recast layer will have a typical thickness of 2.5 to 50 microns and it may be hard and it may contain several pores like pores and micro cracks and it also has the heat affected zone below it which leads to significant change in properties of the workpiece and generally it affects the thermal fatigue properties strength and corrosion characteristics So in the area adjacent to the heat affected zone, so there will be a change in the grain microstructure which leads to change in material property of the workpiece. So here we can see the cross section of the low alloy, low carbon steel where we can see the presence of this white layer which is the recast layer. As this layer suddenly cools because of the incoming dielectric, so we can see presence of certain pores and the vertical micro cracks.

And just below this recast layer we can see this thin layer of material which is having a different sort of a color which is indicated by the heat affected zone and below which we have the tempered layer. So, presence of this recast layer from the top is visualized by presence of this debris and micro cracks and this various these formations are because of the interaction of these sparks at various locations because of which the melting takes place. So, this is basically the top view and this is here is a cross sectional view of any material. And because of these surface characteristics, sometimes post machining operations may be needed with EDM to minimize the presence of such defects on the surface as they compromise with the fatigue related performance of the machined components. This is especially critical with the gas turbine blades as they rotate at high speeds. So in the summary, we can conclude for today's lesson that we have understood about the electric discharge machining process.

In this electric discharge machining process, we have understood the basic relaxation circuit which is the base of any EDM machine. We have understood the process mechanics, process of material removal. We have also understood the basic setup needed to perform the EDM. We have also understood the tool characteristics.

We have understood the role of dielectric fluid. And lastly, we have also understood the process capabilities of EDM, their limitations and we have also in detail understood the presence of recast layer and how the presence of recast layer is negatively affecting the machine components. In the next lesson, we will see the other machining process that is the laser beam machining which is also used to machine the gas turbine blades to create the film cooling holes.

Thank you.