Advanced Machining Processes
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Week - 11
Lecture - 30
Electric Discharge Machining- 1

Hello, and welcome today to this new experiment on the electro-discharge machining process. I think I had earlier illustrated about the EDM drill which was a limited degree of freedom system. So, here today we would be illustrating another kind of machine, the electro-discharge machine, where actually any kind of topology, any kind of operation can be done in a die-sinking mode. I think I had earlier illustrated the basic principle; I just like to recall that of the EDM process. So, there is actually a tool which is made the cathode, and then there is a workpiece which is the anode, and there is always a discharge or stream of electrons which comes from the cathode all the way to the anode to create an ablation or heat treatment of the surface to its melting point. And there is always a tendency to formulate a melt pool, because of this fast electron hitting on the surface of the anode workpiece.

And because of that, there is always also a momentary electron pressure which is created near the surface, which gets dissuaded away very quickly. And naturally, there is some kind of a low-pressure region created, because when the electron goes into the anodic material, the surrounding medium comes and occupies its place, but it has a high inertia level because it being fluid the molecules are heavy to move. And so there is a typically a delay or a lag in filling up the sudden void which has been created by electrons depreciating into the anode, because of which there is a low-pressure region. So, the melt pool formulation because of the strike of the electrons, along with the sudden creation of the low-pressure region would actually get all this molten material off into the dielectric fluid.

And if you circulate the fluid then you ensure that you carry away the material which comes in this way to create the pocket which is like the machined area or the machined surface. This is basically the basic principle of the EDM process. I think I had derived it earlier made many illustrations today. We will see practically how it happens. This right here is a EDM tool, electro-discharge machine.

And you can see that there is you know servo controlled stage here, which actually is able to feed the tool and take it close to the workpiece surface. Here the again the tool is the cathode and the workpiece is the anode here. There are several discharges or nozzles of the dielectric fluid in this region of the machining zone. And the EDM oil which is actually some kind of hydrocarbon is flowed at a certain pressure, at a certain flow rate within this material. So, it always creates a sort of area or a zone where there is immersion of the workpiece and there is some dielectric between the tool and the workpiece.

This EDM can be used because principally it is a die-sinking operation. I remember the way we had solved the electric field between the two plates, which would lead to the automatic levelling of one surface with respect to the other and the parallelism between the surfaces. So, in the same process whatever is on the tool gets imprinted on the surface. It is same as any other identical process like maybe ECM, where the same die-sinking operation would happen. So, here I would show a set of characteristics which are possible by this EDM machine.

You can see here two surfaces, this is the tool surface, this is the tool surface made in copper and this is actually made in mild steel, this is the machined surface. And you can see that it is exactly the replica of another, one another. So, the tool surface is the exact replica of this workpiece surface. And the way it has been achieved is again through EDM. There is a very good setting of these two surfaces, which means that when the machining had been done probably, these cavities removed the materials from the respective zones in an identical manner, thus creating a surface topology like this.

So, EDM that way is a very important process for the industry. Another issue here is that any kind of hardness of the material if it is provided it is conducting can be machined using the EDM process, which may not be a case in metal-to-metal contact machining, where the question of hardness always bothers the tool engineer. And there is always a tendency of the tools to get worn out faster if the materials have slight fluctuation in the hardness value. So, here it is independent of that because the process itself is a thermal ablation process, it is not any kind of contact which is creating the removal in the EDM process. So, in a way that is also very beneficial.

There are other issues or aspects related to the EDM. For example, if you were to sort of map this complex architecture, this is like the comma. So, if you were to map this architecture into let us say the workpiece surface, very easily you can probably do using this non-conventional EDM process. Whereas such a thing if you were to really machine on a CNC lathe would probably take a lot of time. Also, sometimes it is even not feasible, and you cannot get this quality or this finish to do the operation as you can have in this particular EDM operation.

So, you can see here for example, this has been embedded into a tungsten carbide material, which has a very high hardness value, which typically is used sometimes for even tooling in the case of contact machining. And you can see exactly this comma has been embedded onto the surface of this tungsten carbide. And this is only possible, you can see the finish of the machining here, the exact shape has been sort of printed onto the surface, which again gives you a very good illustration of the power behind this EDM machining process. You can also go very small, and this course has a mandate of mostly I would say micro channel-based fabrication. So, you can actually look into the micro features and surfaces, which can be machined using this process.

And I would just like to illustrate that in the EDM there are these collets, which have been specially designed for holding such microarchitectures. There is typically a head for this collet, which comes off, and then there is a possibility that you can you know there is if you look at it very closely, there are jaws on this collet, which would be able to grip this small tool and give a certain positive pressure as the cap slides in and bolts itself to the remaining portion of the collet. It is all of self-pushing action is there, and this would close off so that it can tighten the tool. For example, supposing I were to put this small probably about close to 2 mm diameter of or 1 and half mm diameter of copper, and what to suppose do a similar kind of drilling action on the top of this surface. So, there is a very easy way to do it, you just put it inside this collet, and close the cap.

And so therefore, you can obtain the necessary pressure, and now it has become a sort of tool which can be further held into the system, and used to give a down feed into the workpiece, which can create a hole of probably the same size or same value. You have seen similar kind of holes done before in EDM drill, which is the dedicated system for the drilling action. This is a multitasking system, so not only it can do the EDM machining, but it can also do even EDM drilling. One of the advantages that this machine has to offer is that it actually is able to create blind pockets within systems. So, supposing you were to create a microchannel inside a or on the surface of a metal piece, where the lower end of the channel is closed really.

So, it is like a blind pocket. So, you can easily use this EDM tool for doing such blind pockets. You also saw that this particular example was a case where you are doing the blind pocket. You can see this is a blind pocket, and there are several such pockets which have been created here. So, it is a very similar through-machining operation that would happen in some of the other cases like EDM drilling etcetera.

You can also make various shapes. For example, you know if you look at this feature size closely, this is like a pointed tip, but it is more on a flat that this tip has been created. So, in some cases, you may have to use this for writing something like maybe a square channel. So, you can easily monitor or change the taper, and use this as a tool and scribe on the surface, so that wherever it goes creates a blind channel on that particular surface. So, in a nutshell, that is about the capability and the quality of the machining, and now we will get started with the real machining operation where we want to actually use a workpiece and cut a very complex slot here using a tool which is like a comma.

So, this is like the shape of a comma, and I would just like to cut this or embed this into this otherwise hard workpiece which has been already clamped in the system. So, there is a tool, there is a workpiece holder, there is a bed for the workpiece, and you can actually clamp the workpiece here by using this gripper, this vice. And subsequently, there is a collet specially designed for this particular tool which would hold this tool in place, and you can actually mount this tool all the way to some distance inside and then tighten this lead screw right here which actually gives pressure to hold this particular tool in its place inside the collet. The collet of course is connected to the stage for the translation of the tool, and as I earlier defined this stage is actually servo controlled. So, let me just illustrate a little bit about why it is servo controlled.

You see the EDM process is about establishing of a breakdown electric field of the medium where there is a spark discharge which happens between the cathode and the anode. I think I had earlier illustrated it in great details that how the EDM process would actually go and what are the numerical aspects of the process. So, here the question always is the inter-electrode distance, and this distance has to be below a certain value for the field to go above the breakdown field of the medium so that there is always a sparking condition which is arrived at. And supposing if you were to look at a surface which was wavy-like, and there is another surface which is wavy-like, there may be a case where there are hills on one of these surface, the tool surface, and pointing out to a hills on the workpiece surface. So, there is always a minimum distance condition based on that.

There may be a case that in the tool surface among the waviness on the surface of the tool, a crater which is there or a, let us say a valley which is there, maybe pointing to another valley on the workpiece surface which can be the condition for the maximum distance, and then there can be a hill to a valley or a valley to a hill between the two electrodes. So, in all the events there are different distances which are formulated with the minimum distance between two hills pointing each other between the electrodes, the anode and the cathode. You have to remember that irrespective of how hard we try to finish machine, there is always going to be some kind of roughness in the topology on the surface which would be the cause of these hills and valleys. And therefore, if there is a voltage V between the cathode and the anode, and the electric field you know is voltage per unit distance, so smaller is the distance, the higher is the electric field. So, therefore, a hill facing a hill with minimum distance would correspond to a maximum electric field, and if this field goes down the breakdown field, there will be a discharge, and this discharge would create the distance to again increase, because now the spark has come, it has stricken the workpiece surface, it has created a melt pool, the melt pool goes away, and there is now a crater facing the hill.

So, in a similar manner, once this process has been disestablished, and the dielectric fluid has destroyed the iron column, the possibility of another spark does not happen, unless the voltage is increased a little bit, or the distance is decreased a little bit. And so, a servo control here is very important to do that, monitoring of the voltage across the gap, and trying to make the distance go down to another value where the breakdown field will be hit upon. So, always there is a control based on the gap voltage monitoring, and this voltage should be over and above a certain value, assuming a small inter-electrode distance, so that the field always goes down the breakdown field.

And in fact, there is a PID which has been designed here, where it can actually give the servo a command to go either towards the workpiece or away from the workpiece, based on if you want a sparking or a de-sparking condition in the machine. And in fact, what we are trying to do is, we want to give a pulsed signal rather than a complete DC signal, and then there is a tendency of some relaxation time given in the process because we want to get rid of the ion column every time it is formulated.

So, this is another important issue I think I had mentioned during my earlier classes, where I had talked about that you do not want to repeat the spark to go in the same zone again. And how is the spark really created? It is a plasma which is formulated in the medium with ions and electrons, and the electrons rushing towards the workpiece surface. And so therefore, a continuous flow of the system would ensure that the column gets destroyed once the spark has been delivered from the anode to the cathode. However, this is an operation which is a little bit laid back, because of the high inertial level of the medium with which you are flowing, and there is always a tendency of sometime gaps between which there may be the re-establishment of another sparking process, particularly because the path that has been formulated here is a conducting path. So, you have to ensure that you give it enough relaxation time, where the voltage is, pulsed voltage between some V value and zero, so that once the voltage comes to the zero value, you get that time for relaxing the medium, so that the new material can flow in, the dielectric fluid can flow in and destroy the ion column, so that the same spot cannot be used for sparking twice.

And one of the reasons why in EDM operations you see spark dance all around is that whenever you were actually doing the servo control to take the distance or you know change the inter-electrode gap, there may be another region which comes up where there is a hill facing a hill, and a problem of minimum distance and maximum electric field comes where there is another spark. So, the spark would be dependent on wherever the hills are facing each other on a surface, provided there is servo control. And on the other hand, we have ensured that by giving a switch on switch off time and a pulsed signal for a particular amount of time during one cycle, you are actually letting the medium to relax, so the ion column vanishes away, and it is ready for the next discharge process to happen. So, with this I think the fundamental part of the machining that you need to understand is kind of done, we want to now go ahead and do the machining. So, the first thing here that we need to take care for the machining is the tool positioning system, and we had done a similar kind of operation earlier in the EDM easy drill.

So, here there is a manual system of control which is given by these two axes, motion controlling axes axis, and then also there is a control which is given to the servo system right here which drives this tool and goes towards the workpiece actually. And doing this is not a problem because you can actually use these up and down arrows in order to do this controlling. So, you can actually press up and down and let the tool either go away or towards the workpiece surface. So, here what we are first trying to do is to sort of position the tool in a manner, so that it is in the centre of this particular workpiece. We want to drill this hole, we want to do this blind pocket, we want to machine with EDM exactly the geometrical Centre of this particular cylindrical workpiece surface.

So, in order to do that we tentatively move this tool in the x and y direction. So, basically you can take it all the way to the centre here, and then also you know in the y-axis towards the centre. The machine is designed in a manner, so that it has two covers as you can see here, right So, you can take it here and these are you know sort of sealing, self-sealing covers because ultimately this is going to contain the EDM oil etcetera like a tank, it is going to behave like a tank. So, there are some seals or sealings which are there on both ends here you can see which would actually prevent any leakage from happening. But why the covers are open is that you have to manually do the adjustment by seeing across the x and y axis in this direction as well as in this direction, and you are able to position the tool based on that particular reference.

So, once the tool has been positioned, and you can actually take it down a little bit more tentatively in the geometrical centre. In fact, a better idea would also be to sort of you know mark this tool with some kind of a die and take the impression on the workpiece surface to actually locate that where the tool if it is a complex architecture is positioned with respect to the workpiece. So, we just take this down a little further, and then tentatively we can actually see that it is in the geometrical centre from both sides. So, once we do that then we leave it to how you know to the controller to do the programming action. Let us actually investigate what is there on the controller.

So in fact, there is this punching box which is there in this machine for doing the various or punching the various commands, and this right here the screen what you can see is the display of the controller. So, this is actually the controller unit which would do the servo control action, and here what we can do is by standing at a little bit distance we can actually do this controlling. So, there are various aspects of the controller, and the first aspect that I would like to mention is that irrespective of whatever may be the display here you have to escape the existing command. So, right now it is in that mode it is initialized. So, therefore, anything on this controller which says escape, there is a button for the escape you just do this escape to quit any of the programs that may have been running from the earlier runs or any of the process settings that may have been restored from the earlier runs.

So, once the position has been escaped, so this is how the program you know looks like on the display, and if you look at the line which is towards the end of this in the bottom portion of the screen you can find various functions F1 to F10 where it is indicated individually what F1, F2 or as a matter of fact F5, F9, F10 would do. So, here the first goal that we have is to actually go and enter into a program which is already been done. It is a good idea to sort of modify an existing program and save it under a new name rather than doing the job setting although that option is already there as F9 to do the direct job setting, but we generally prefer because there are lines written in a program. So, in order to avoid the wastage of time you can actually save this program in a different name etc.

Once you have re-modified the program. So, we go to F10 first, and you can see that it has led to another sort of command line where it is talking about program number selection, the start block for the program, the end block for the program, even the abort, the program abort option. And then some two other options EZ Guru and Tech which actually gives you the detailed description of the process as such or the process details related to the EDM. And then there is F7 which is corresponding to save as and similarly F10 which is actually related to the flags. So, the flags actually can be obtained on the right upper corner of the screen here where it talks about various options like whether the buzzer should be off or on, whether the Z lock should be off and on, servo, whether it is going to be in the normal position, whether the display is going to be in the absolute mode or the incremental mode. So, all these different aspects are being looked at as the basic initial guidelines for setting up a process.

So, we want to first actually change some of these flag properties, and you can say that you know it is about the way that the machine would read the programs to an extent. And here in this particular case what is important to us is that right now the buzzer as you can see is in the off mode. We want to make this into the on mode because then we will give it an indication of the start and stopping of the process or even when there is a no gap you know in between the electrodes there would be a buzzer sounding off. So, what we are going to do is to sort of go to the flags and then use this cursor, up cursor and go all the way to the, you know you can see the text getting reddened as you toggle between the various options. So, you can go all the way up to the buzzer and then with the page up and page down you can actually turn this back on.

So, that now the buzzer is actually turned on. And similarly, you can do the Z lock which means that you can lock the Z axis. The servo can be in the normal mode, normal mode of operation. And then of course, the display can be in the absolute mode of operation. So, these are some of the details, machining details which are important to be saved here in this process. So, once you have done that we go to F10 again back because now we are talking about the job set option.

So, we just go to that job set option and you can see here that as soon as it has been done we are in a position to actually set up the x, y, and z values using the various functions and try to make a sort of reference zero for the machine from which the machining would start to take place. So, we want to first now set up the z value and make it auto-position on the surface so that the gap can be close to zero. This could be the zero reference. We did the similar manner of the easy drill as well. So, you go all the way to this toggle board or this you know punching board and there is an auto-positioning option right here which we have to sort of press now so that there is a slow movement of the machine until the machine touches the surface that is in question.

So, you can see the buzzer now sounding which indicates that the gap has closed of the machine. Again, we go back to F10 because we had to escape that mode in order to do this saving option and then we already have the flag set. So, we go to the again the F10 with the job setting. So, we are back to the same screen here and you can say that there are different these x y z values which we now need to zero. So, the first thing we want to do as the gap has closed on and it has been set to zero between the electrode and the workpiece surface is to basically go to the z value using F4 and you can see the red cursor coming on to the z value here and we want to set this value to zero.

So, you punch zero in the punch board here and automatically this would be accepted as zero value for the particular system. So, you basically once you have typed zero you set enter value so that this is the machine zero for the z-axis. You do a similar thing for both the other x and y. So, we go to F2 which indicates the x motion make that zero as well zero and enter and similarly go to F3 which makes y and then you basically make that zero and enter so that these all x y z's are now set to the machine reference position through which the machining process will begin as 000. So, once we have done that then the question of going into the program happens because supposing we want to actually set up a certain time on value or pulse time or several other aspects related to the machining.

We have to now individually go and modify the command blocks. So, this whole thing is called block of several commands and there are several such blocks in series which would actually start at a certain position here you can see s option meaning thereby this is the start of the block, and e option which is end of the block. So, there is a scanning of the blocks you know the scanning of the commands in a line-by-line manner in a block-by-block manner till the whole program gets completed. So, basically now we come to set up this program actually and for doing that the first thing we have to do is to sort of vary the start and the end positions on the various command lines that you can see here. In this particular case for example, the start position is at line 4 and the end position is at 5.

So, I would like to build my program where I want to start it in the line 1 itself. So, what I am going to do is to sort of go to this F10 program mode. The F10 here is program mode and then I can actually take this cursor to the you can see the cursor being moving across the various command lines. So, I will go to this first line the first block of the command and I will make this the start position the new start position by pressing F2. So, you can see that the start has come from line 4 to line 1 because of that.

Similarly, if I can go scroll down here may be command 3 is the one where I want to really end the machining process. So, I can make this F3 so that the end has now shifted, and the program is now between the line 1 and the line 3. So, it executes line 1 first then in the same sequence it executes line 2 and then it executes line 3. Then we can change the independent values of the x, y, and z and the way that we want to do it is by following the conventional CNC nomenclature. I think let me just recall that the CNC programming in that aspect when particularly you are doing the absolute positioning mode you have to consider that whenever the tool is moving away from the workpiece or tool is moving away from the job it is treated to be the positive z motion.

So, actually the movement here being a sort of die-sinking activity is mostly along the vertical motion unless we decide to sort of you know print a whole channel or a whole feature over several different lengths of the workpiece. So, only that event we need to use a different value of x, y every time, but here for example we are just wanting to die sink a particular complex shape into the system. So, we want to only use the z axis for that and here we will say that if we are going into the workpiece and into or towards the workpiece the z axis would be negative. So, basically what we are going to do on the CNC program is to give a negative value of the z-axis so that this tool can actually die sink into the workpiece and mind you we had already set up a reference zero position before from which the drilling would actually start to take place within the workpiece material. So, let us now go back to the screen here and try to change the various parameters and for doing that I would just like to illustrate that there are you can see several parameters on this command line.

Of course, the block has x, y, and z values which does make sense, but then there are different other options like Ip, Ib, Ton, t, Vg, SEN, ASEN, TW and Rd. So, I am going to now slowly describe one by one what these parameters do or what they mean and for that I have to refer back to the manual of this particular process where the different parameters are given. Of course, as you may understand the x, y, and z values do represent the x, y, z displacements. So, the case in this machine can vary between minus 999 to about 9999 millimeter's range and similarly, the same goes true for y as well as z. So, that is about defined by the state size of this machine which it has and how it can move, and the span can be accordingly programmed.

The other aspect is the sparking current Ip which is actually the fourth, the fifth line on this particular block where it says Ip, and this basically is commensurate with the sparking current. So, this is really the current at the time of sparking of initiating of the spark from the tool to the electrode surface. There is a line Ib which actually suggests the pulse current. So, therefore, this is actually just pre-sparking condition where you have given the voltage pulse to the system.

There is a certain current which flows and that is limited by that. So, here as per the machine manufacturer, a maximum of 200 amperes can be programmed for normal machining purposes in the Ip value and it can start from 0 anywhere to 200 ampere. Similarly, the Ib value that is the pulse current value can be set between 0 and 5 amperes. You have to understand one thing that the current which is the sparking current is much higher in comparison to the pulse current because of the fact that sparking actually is an electron discharge and this happens at an extremely high value of charge. So, basically the point from which the spark has emanated is actually across the dielectric gap and we are measuring the current flow across that gap which would only correspond when the electric field breakdown has happened of the medium which means that the amount of charge that has been stored in the particular instant or moment of time on the tool electrode, the cathode is so high that it results in a very high momentary discharge of that electron and one of the reasons why the current value is very very high in that particular case. There is also a t on here which represents what is the portion of the pulse where the voltage actually from the power supply is on.

You will of course, add a duty cycle factor to it which means that further you can actually make a 100 percent duty cycle where this whole time on that means the time for which the voltage is supplied to the electrode is utilized or you can make a subsequently lesser percentage where you have a on time and a off time in the same pulse. So, if you are creating a time on here the manufacturer again says the pulse on time can vary anywhere between 0.25 to about 4000 microseconds and you know you can place the percentage duty cycle anywhere between 1 to 12 percent. So, the maximum utilization that you can make of a whole t on is only about 12 percent the whole time that you are suggesting here. In this particular case for the particular sample that is in use, we want to use a Ip value of about 10 amperes and this is more an experiential gathering and there is some kind of a literature survey which you have to do for different materials to come to this particular estimation.

The Ip value we want has about 5 amperes and then the t on the pulse on time here that we are setting is about 75 microseconds. So, the duty cycle of 3 percent meaning thereby about 2 microseconds between that 75 microseconds is actually the on time and the remaining 73 microseconds is the off time. So, that is how the duty cycle is signifying. So, therefore, the actual time for which the voltage is being supplied to the tool is very small in comparison to the full pulse on time that has been set here.

And then of course, you have the gap voltage. So, the gap voltage as you know is has to be set commensurate with the breakdown field. The field depends on two properties again. One is the voltage difference between the tool and the workpiece, and another is the gap between them. The gap in this case is extremely small making the voltage to be reasonably high so that the electric field goes to a very high level overall. So, here the voltage that we are going to set is about 40 volts although there is an option of going all the way to about 150 volts and in some cases up to 240 volts.

So, that can be probably there is a selection switch in the setup menu where you can vary the voltage between 150 to 240 volts so that the maximum limit can be extended that way. There is also ASEN which actually means sensitivity of motion of the quill or the tool holder in this particular case. And we need to actually illustrate what is the level of sensitivity of motion meaning what is the response and how important this is for determining the you know the voltage gap or determining the servo conditions. So, if I say that it is a high sensitive system therefore, lot of emphasis is given on to the gap in comparison of I say it is a low sensitive system. And then again you have a anti-arc sensitivity and the sensitivity in this case can be changed between 1 and 10 meaning thereby 1 is on a lower sensitivity scale that means the gap may be not so much matterable for controlling the servo and 10 is probably the highest on the sensitivity scale meaning thereby the gap is very highly sensitive and servo controls based on almost the gap value.

This is how it has been set by the manufacturer. And then, ASEN is basically the anti-arc sensitivity. You have to remember sometimes that instead of making a spark there is a arc formulation which happens in this process because if the tool dwells or the voltage pulse or the I would say the ion column dwells in a particular region for a longer time there is a continuous flow of electrons from the tool cathode to the tool cathode to the workpiece anode. And this is the condition which we must avoid in EDM because EDM actually is about all spark machining, it is not really arc machining. And for preventing that from happening one of the reasons is why we do the flow of the dielectric is to sort of destroy the arc column being formulated. But sometimes it does not happen and therefore, there is an aspect of the sensitivity of the system here again that how sensitive the system should be to this anti-arc you know.

So, here we are making less sensitive because of the fact that maybe the machining of this material is not that hard in this particular case. It is only mild steel that we are going to machine with the copper tool in the shape of a comma that has been earlier demonstrated to you. And then of course, there is these two other parameters TW and Rd which actually the total working time which in this case comes out to be about close to between the start and end of the block it is about close to 11. So, close to about 11 and a half seconds you know if you look at all the three different times working times it is 3 plus 4 plus 4.2 so 11.2 seconds. So, that is how we are programming it although you know you can actually go all the way up to 30 seconds to support the machining operation in this particular case as defined in the controller by the manufacturer. And then of course, the retraction distance is the sort of you know distance up to which the electrode will move away from the job. And you should take due care so as to avoid any collision while setting up this parameter because naturally if it collides then there is no you know I mean there is no reason why retraction should happen. So, the retraction distance in this case can be set all the way to 20 mm.

So, we are actually keeping this value at about 2 mm. Whenever there is a case where there is some kind of a shorting the tool would automatically retract to a distance of about 2 mm thus creating an inter-electrode gap of the same value that is what this whole system is about. So, we have kind of programmed our controller in a manner so you know you can see that in the line 1 you have x, y and z values all zeros and we have kept the Ip the current to be 10 amperes, the Ib to be 5 amperes, the ton to be about 150 microseconds, the percentage duty cycle that you would like to give is about 3 percent which meaning therefore, meaning thereby that we use the total pulse on time for about 4.5 microseconds. Obviously, because this is an initial cut we are trying to at the first step trying to just give a hard cut to the hard surface and beyond a point when the cutting would start, we can actually subsequently reduce these ton times. The Vg value the voltage gap voltage is about 40 volts in the first case, the sensitivity of the quill is about 4 and the anti-arc sensitivity is kept at 1 and also the working time is kept at about close to 3 seconds and the Rd that is the retraction distance is about 2 millimeter's.

So, when we go to the next step you see there are this is the first cut really that would happen after the initial surface has been sort of hardened. And here you can see that the only change that is there is in the y in the z value and the z value is minus 12 meaning thereby that it goes 12 mm within the surface. I would like to just illustrate here that it is just as per CNC programming you have a surface in absolute mode. So, anywhere the tool approaches the surface or goes into the surface is treated as negative and the tool goes up away from the surface it is treated as positive z-axis motion. In this case it is a negative z-axis motion just in case of drilling or hole-making where you are going within the surface.

So, therefore, it has to be negative. So, minus 12 and then, of course, we have Ip value. Now, this is said to be about 8 amps because now the hard cutting which was actually needing a lot of sparking current is no longer leftover because the surface integrity has been lost in this particular case because of the first cut. So, this is said at 8 amperes. There is a total you know the Ib value of about 5 amperes in this case and the t on also has been reduced to 75 microseconds where the 3 percent duty cycle meaning thereby about 2 seconds or 2.5 seconds I would say the wait period or the dwell period for the voltage to be on or it is that 3 percent of the total time cycle being used for the actual voltage being added on the tool.

The gap voltage is kept at 40 volts it does not change much because and then sensitivity of the quill has increased a little bit because now the motion of the tool because it is going the workpiece becomes a little bit critical and the sensitivity should be higher for the servo controller to be able to closely monitor the inter-electrode gap because of that. The arc sensitivity also is enhanced a little bit to 2 and then you have the TW the working time is now increased to about 4 seconds and Rd the retraction distance also is increased because it is already get to a depth of about 19 millimeters. So, the retraction depth is now kept at about 5 millimeters. So, these parameters are set almost by experiential in an experiential manner with the prior cutting experience of the particular tool with the particular electrode surface that we are talking about also in the end step now there is a final motion of the tool where you can go the additional 7 millimeter's over and above the 12 which had been cut in the last step because it is an absolute mode of programming we say Z equal to minus 19 here from the surface just as the first step was minus 12. So, the total amount of motion would be in absolute coordinate mode be referred to as minus 19 although the actual motion between the two positions is only about 7 millimeters.

So, you have Ip here slightly lower current value because this is sort of the end of the process. So, you need not keep the spark current to be very high this ensures also a kind of finesse on the surface a fine finishing on the surface because of smaller current value the Ib current is also the kept as about 5 amperes, and then the t on has been now reduced to 50 microseconds and utilizing 3 percent of that time. So, about 1.5 microseconds is the really the application of the voltage pulse and then the Vg value the inter-electrode voltage is kept at about 40 volts same the voltage does not change much because this is the quantity which controls actually the servo gap or the servo motion the gap voltage is the main quantity for that.

The sensitivity in this case is even higher because it has gone down further to 19 mm. So, the sensitivity is given on a scale of 7 here close to 10 and similarly, the arc sensitivity also is increased to 3 and total working time here is kept slightly above what happened in the earlier minus 12 steps. So, because it is actually at a certain depth, and we want to make sure and also it is for a lower current value. So, we want to make sure that the whole has been completely carved out up to the depth of minus 19 mm one of the reasons why we are keeping the working time to be about 0.2 seconds more than the earlier step and then of course, you have about 10 mm of retraction distance because it is further down the hole therefore, the retraction distance is in this case has been increased. So, having said that this completes the end of the program this is the end block, and we are now all ready to go for the machine to do the micromachining activity.

So, now we want to close this tank remember this is the ED tank which is used for the dielectric fluid. The fluid will actually fill all the way up to the tool. So, that it immerses the tool as well as the workpiece on the in between the oil dielectric medium and then you will have force flow through these nozzles which will always maintain a circulation in the zone of machining and is very important for destroying the iron column created again and again. So, I am going to now close this tank and this as you know is like a sort of liquid-tight compartment and therefore, there are these heavy-duty clamps which would do the job of meshing the two sides together with the seal in between.

So, that the oil does not come out. Now, we will go for the next step which is filling of this tank beyond which we will start the machining. So, here now we would like to give a little bit of illustration about the dielectric dispensing system associated with this machine and for doing that what is important is that there are different valves on this machine as you can see which perform different functions. One of them is to actually control the flow in the local zone over this particular area right here which does the machine, machining. So, supposing there is a earlier machined area from which there are excerpts like chips etcetera coming out of the process. So, you have to wash them with high-pressure fluid and for doing that you need a high pressure to be injected to this particular zone by circulating the dielectric fluid and pressing it in a manner so that it flows in this particular zone.

So, what we are going to do is to use again the punch box here right here. If you look at the punch box there is an option of you know oil flow or pump flow in this particular case here given by this option where I will switch it on and this generates a certain pressure in the system which actually leads to the oil flow and what I am going to do is to sort of if you look at this area, if you focus on to this area you can see that by changing the position of the valve I can actually flush this area with dielectric fluid which is flowing to sort of ensure that all the chips etcetera are carried away from that area once the process begins it should be clean, completely clean. So, there are these nozzles which are now firing. This can be after some washing time closed and then whatever is being pumped is right now drained out from the system because the chips need to be drained out. So, you wait for some time till the whatever chips have been washed off goes out of the system and then what you do is the following. You basically use this lever and try to close the valve so that the EDM oil in the tank can now start rising.

You can see that the oil level is now started to rise because of the closure of the valve. It is not been drained anymore and one important thing here is basically the level of the oil which is basically given by this indicator here which can actually change positions and which can also give you an illustration up to what level will prevent sparking or you know in air, dry air. So, you do not want it to be a dry EDM process. So, you want to at least ensure that this pointer is in the level of the at least the tool holder which is actually placed somewhere here. So, now once it has been set up it gives you a complete control of the process and you can fill this tank up with the EDM fluid and then perform the EDM operation on this particular sample.

You can see the EDM oil level coming up. It will come all the way up to this indicator here and will stop the pump after that. So, now we are actually left with the situation when more or less the as you can see here the pointer is quite submerged within the dielectric fluid. And now we have also started the flow in these regions by opening the valves for the nozzles in that particular EDM area and we all need to do the machining finally. So, you if you focus on particular toggle switch or the this punching box you see there is a spark option which is here.

So, all you need to do is to create this spark on. So, that there is a EDM action which is now happening. If you go close by in the tooling system you can see that there is a spark which would be created because of this particular process and this spark here can be easily visualized if you switch off this lamp actually. And you can see here that there is a intermittent sparking action which is actually coming in the zone which is being machined and you will have the exact die of the process sink into the system. So, that you have a part made in the particular sinking system. There is some kind of a vaporization action which does happen which you can capture on the camera and one of the reasons why that is so is that there is going to be a pyrolysis of the EDM oil to some extent which will also create subsequently a layer deposited over the tool side of the surface. So, there is some kind of a chemical pyrolysis along with the physical breakdown of the ions and the electrons which happens in this particular process which creates you know the which creates a problem sometimes for the EDM because if a tool were not to be dressed properly and used in EDM for a long time, the pyrolytic layer which deposits out of the breakdown of the EDM oil would cause the current to somehow get blocked and the EDM can be self-stopping process in that case.

So, you need to sort of after 2-3 runs take out the material and be able to sort of you know dress it properly so that the pyrolytic layer on the surface gets removed every time. So, as you can see now the tool has returned back to its initial position after doing the EDM machining. I just take up this punch board and then I just try to switch off the pump by pressing this and then we need to somehow drain this EDM oil which has been filled up in the tank. So, I am going to go ahead and just make this lever in the on position so get drained and the oil is actually now going out and you can see that the oil level inside this tank is receding. So, it has to go all the way to you know the bottom before we can retrieve the workpiece and as I will show you there is a cut which has happened to this workpiece actually in this particular case by removing the workpiece.

So, you wait for the oil to sort of upside down and then we can actually retrieve the workpiece. So, you have to just open these clamps here and just declamp this so that you can open up the box in both the cases and this is how. So, you can actually open this cover as well as this and then the whole idea is to be able to extract this workpiece from this jig here. So, I will just like to show you how the EDM process has been done on this particular workpiece and I will just get rid of the oil and you can see that the shape that we were intending to was that comma-shaped object of which the electrode was is being now imprinted on to this surface and this can go up to all the way from hundreds of microns to almost about few tons of mm's and that is the advantage behind EDM that it can go up to any extent. So, just because we are talking about micro here, we have taken the workpiece out and the process is still not completed its 19 mm depth which was actually earlier shown in the CNC code.

We just wanted to show you that how this shallow channel or shallow feature would look like on a surface. However, I will just show you another workpiece which has been recently completed which would actually correspond to the you know higher feature depth. This is the case of 18, 19 mm you can see that the comma has been inserted all the way to about 19 mm in this particular case also. So, therefore, I would say that you know various depths particularly from few tons of few tens of millimeters to all the way to the micron levels can be made using this very important and useful process. One of the things you have to remember about EDM is that it is really a non-contact process and irrespective of how hard the material is you can still be able to do machining because the way that machining happens here is purely by thermal ablation. Of course, there is an issue about the final surface texture and the roughness which is again very important parameter as I have illustrated several times earlier in the lecture.

And there are different studies which talk about what would be the ideal machining parameters for the roughness to minimize in the particular case. But in any event sometimes particularly in construction of micro devices, we may need hybrid processes where at the first step the basic machining is done using EDM and in the next step again some other etching process or suitable fine process has to be done over the EDM in order to obtain a smoother channel a smoother surface or a smoother micro device as the objective of these courses. Thank you.