Advanced machining processes
Prof. Vijay K Jain
Department of Mechanical Engineering
Lecture 33
Electrochemical Spark Machining

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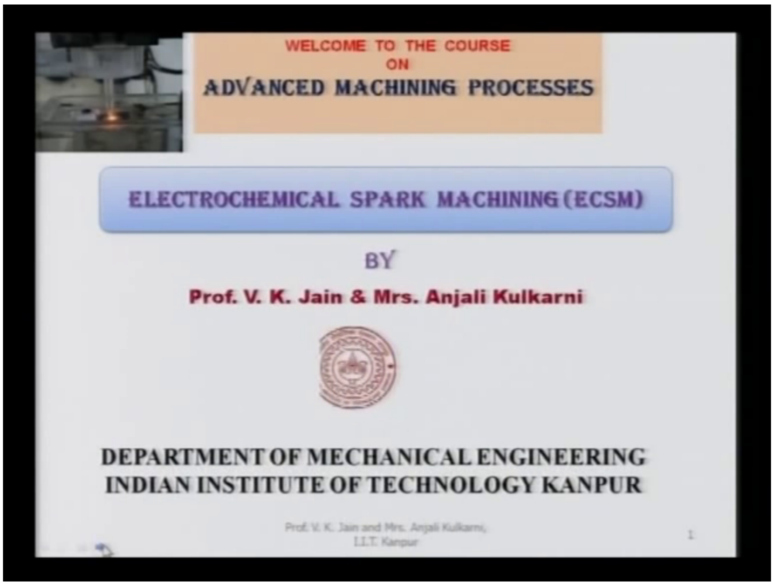

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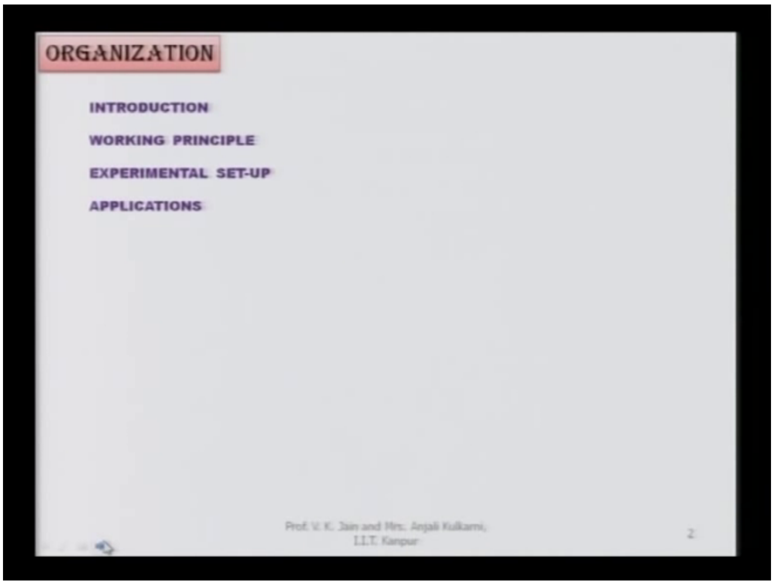

Welcome to the course on advanced machining processes. Today we are going to discuss the topic on electrochemical spark machining which is abbreviated as ECSM process. The organization of today's talk is as follows introduction working principle of electrochemical spark machining process. Experimental setup of the process, applications of the process.

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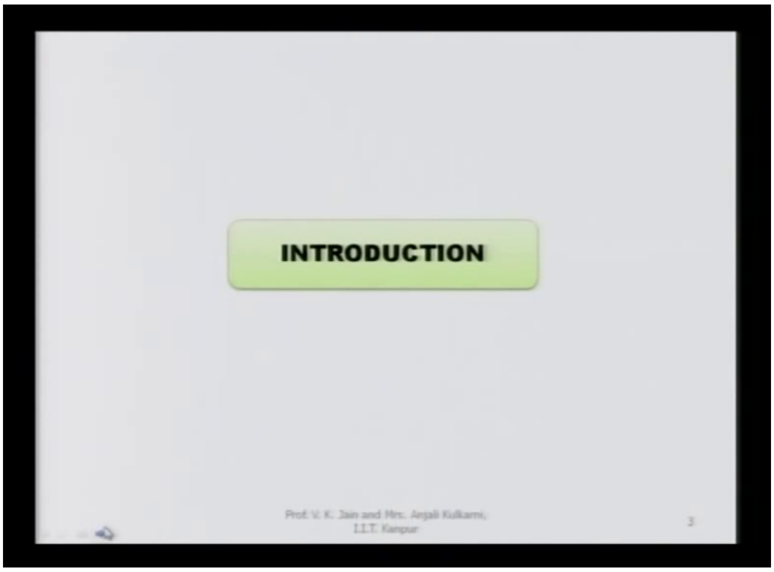

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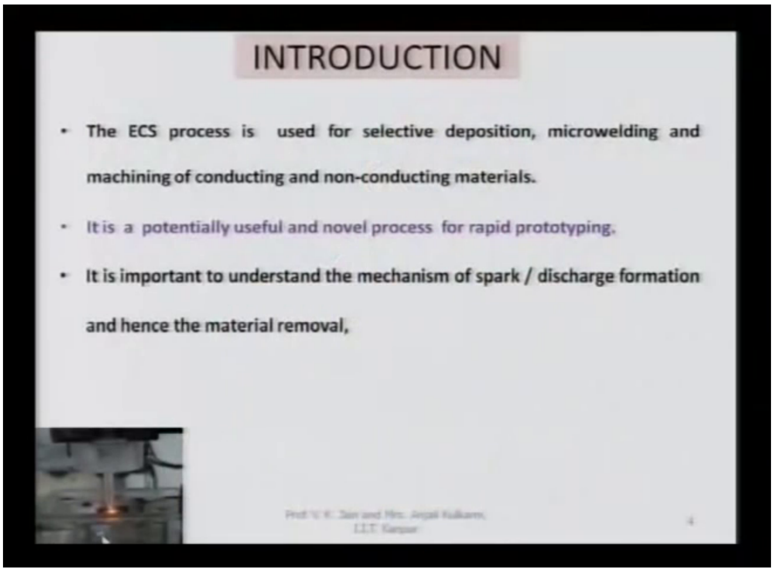

Introduction, the electrochemical Spark process is used for selective deposition, welding or micro-welding and machining of conducting as well as non-conducting materials that means this process can be used for electrically conducting as well as electrically non-conducting materials. I will like to mention here that for electrically conducting materials there are various processes already available such as electrochemical machining, electric discharge machining and some other processes but very few processes are available which can be used for machining or micro-fabrication of electrically non-conducting materials.

So this process is an unique process which can be used for electrically non-conducting material and it is the hybrid process as I will discuss little later which combines ECM process and EDM process and both these ECM and EDM processes are useful only for electrically conducting materials but the hybridisation has led to its hybrid process utilisation for electrically non-conducting materials.

It is potentially useful and novel process for rapid prototyping also. It is important to understand the mechanism of spare discharge formation and hence material removal. As the name indicates that spark is responsible for removal of the material that means it falls in the category of thermal process.

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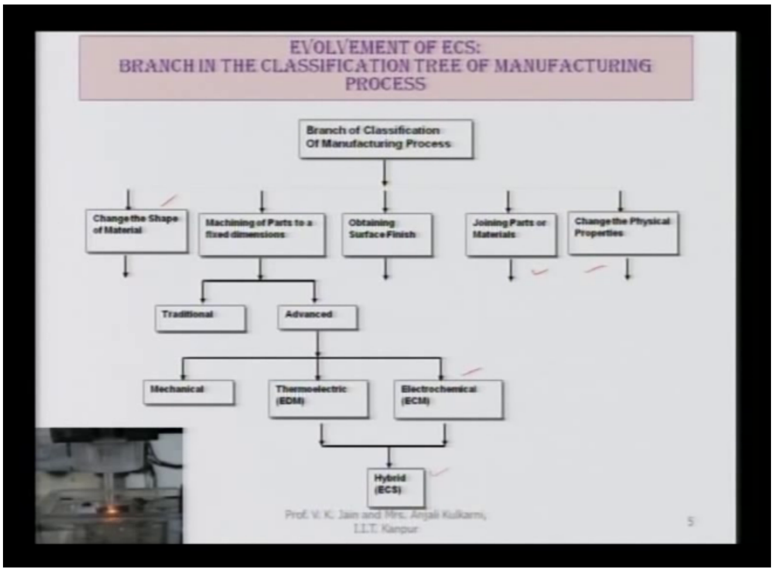

Involvement of electrochemical spark, as you can see here branch in the classification tree of manufacturing process, you can see here the classification of manufacturing processes like change the shape of material, machining of parts to a fixed dimension. Here you have traditional and advance both in terms of advanced you have mechanical type, thermoelectric type, electrochemical and chemical processes as you can see here and then you have the hybrid processes and electrochemical spark machining falls in the hybrid process. We are not going to discuss finishing processes or joining processes physical properties processes.

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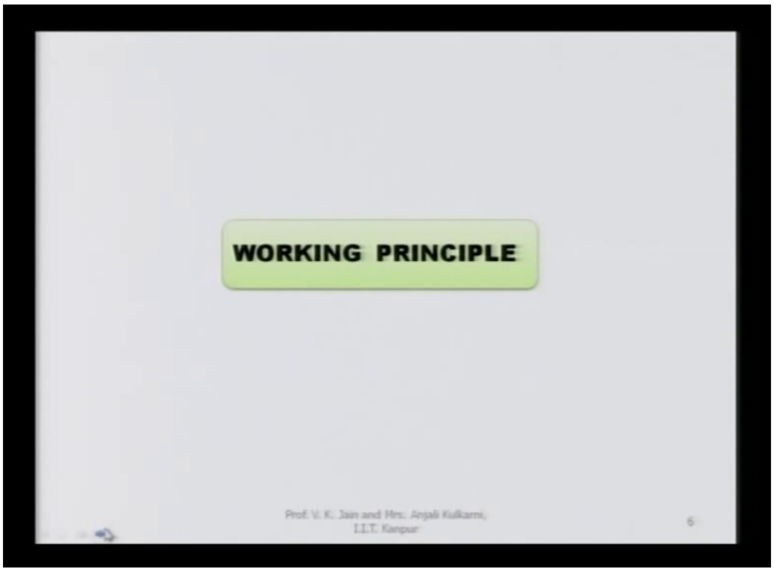

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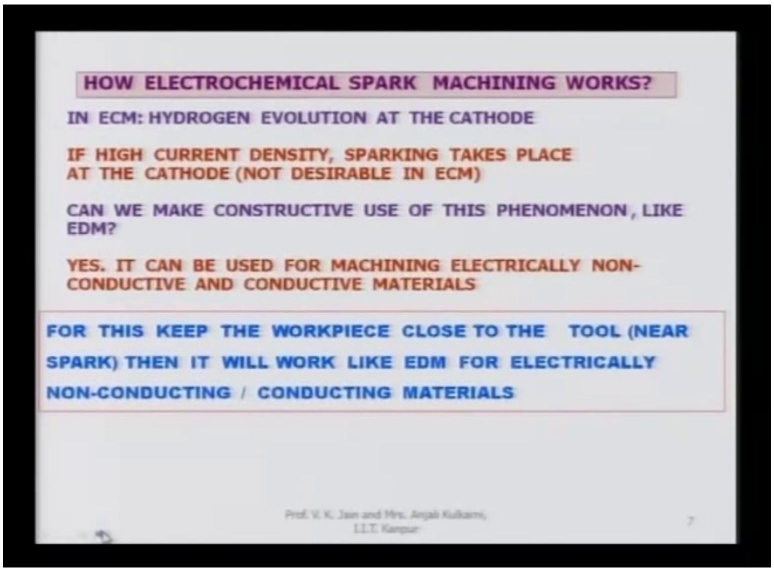

Now let us understand the working principle of electrochemical spark machining process. How electrochemical spark machining works. In ECM as we know hydrogen evolution takes place at the cathode in the electrolytic cell and this takes place if high current density is there between the anode and cathode then sparking takes place across this hydrogen ball which is evolved at the cathode.

However we know that this is not a desirable phenomenon in case of ECM because it is going to damage both tool as well as work piece because in ECM the material removal takes place by electrochemical dissolution not by sparking phenomena. Now the question arises can we make constructive use of this phenomena that is sparking phenomena? Like what we have in case of electric discharge machining process where spark is being used for the removal of the material and this EDM process gives good dimensional accuracy as well as good surface finish.

Then the answer to this question is yes we can make constructive use of this spark which takes place across the hydrogen gas at the cathode, it can be used for machining electrically non-conducting and electrically conductive materials. For this purpose keep the work piece close to the tool near the spark because spark is taking place at the cathode that is the tool, so keep the work piece near the cathode then it will work like EDM process for electrically non-conducting as well as electrically conducting material.

Because an EDM also, what we are doing? We are having the spark across the 2 electrodes, one of those electrodes is work piece another is tool. So since work piece is , so close to the spark or the spark is taking place on the work piece itself, so that heat which is evolved due to sparking is responsible for removal of the material in EDM process. Same phenomena takes place in electrochemical spark machining if we keep the work piece very close to the spark taking place at the cathode.

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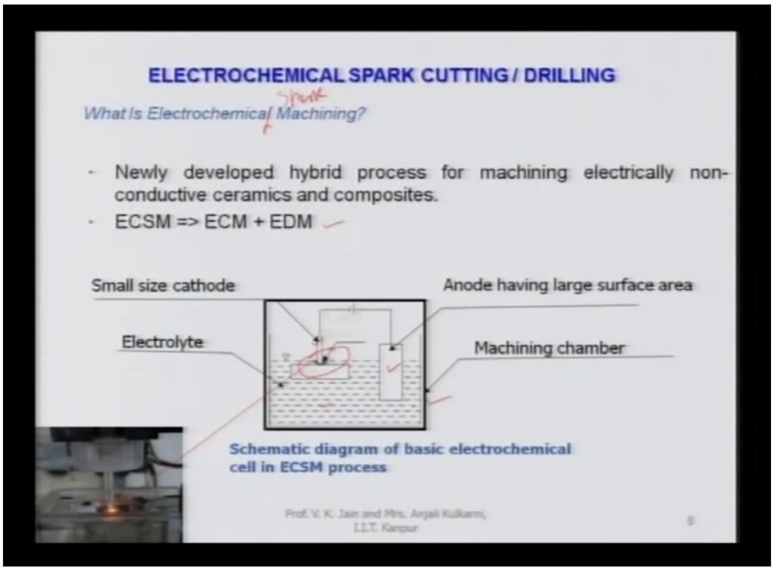

What is electrochemical machining? Newly developed hybrid process for machining electrically non-conducting ceramics and composites. So what is electrochemical spark machining not electrochemical machining? And you can see here electrochemical spark machining ECSM is hybridisation of ECM process and EDM process. This figure indicates the working principle of electrochemical spark machining process, you can see there is a machining chamber and in this chamber, this chamber is filled with the electrolyte you can use various kinds of electrolytes as we have discussed in case of electrochemical machining process and then you have a anode which is of quite large size compared to the cathode as shown over here.

Now you can clearly see this there is a big difference in the size of the cathode as well as anode. Now what is happening? As shown here that bubbles are generated as you can see, bubbles are generated at the cathode and due to high potential gradient across the bubble sparking takes place and you can see in the side left figure shining spark has taken place over there and this is the picture of actual setup where sparking was taking place.

So this sparking takes place across the bubble on the cathode and the work piece is kept very close to the cathode, so whatever heat is generated in the spark part of that heat is transmitted to the work piece and this heat is responsible for melting and or vaporization of the work piece material and this is exactly the same principle as that of EDM. Now when melting or vaporization takes place you can get the replica of the tool in this particular case also that is electrochemical spark cutting or drilling process. So it shows schematic diagram of basic electrochemical cell, this is called as electrochemical cell.

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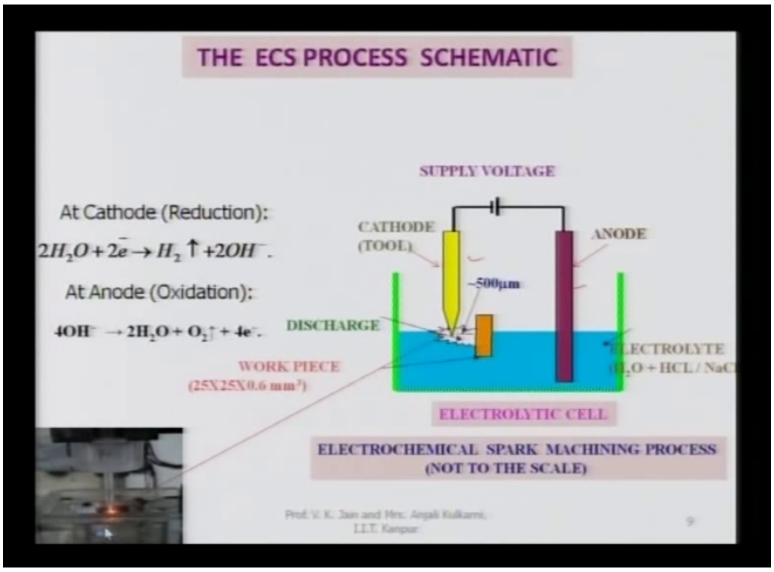

Now this is another picture of the same electrochemical spark processes schematic, this is electrochemical cell, electrolytic cell again anode is there cathode is there the gap between the cathode tip where spark is created and the work piece top surface is around 500 micron. Now you can see here that work piece is neither cathode nor anode. So it can be electrically conducting material, it can be electrically non-conducting material and discharge is taking place very close to the work piece that's why the heat generated in sparking is transferred to the work piece and that melts and vaporizes the work piece material.

Now there are certain chemical reactions that are taking place, at the cathode electrolysis takes place and you have 2 H2O plus 2 electrons you get hydrogen gas which is evolved over here across which the sparking is taking place plus 2 OH Ions. At the anode oxidation takes place and 4 OH they form 2 H2O plus O2 plus 4e. Now then there is further dissolution of the material from the anode and we do not want dissolution of the anode. So we can use such kind of anode material which does not dissolve in this particular configuration. Normally the anode is made of graphite.

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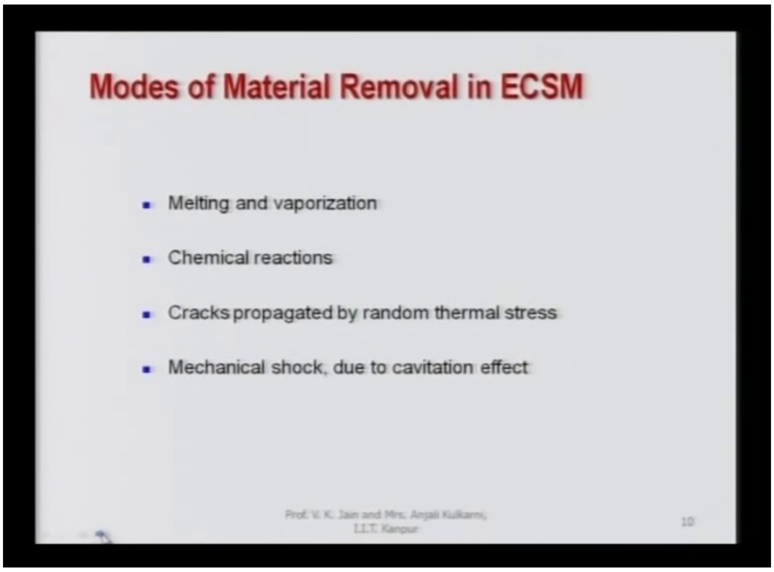

Now in electrochemical spark machining there are various modes of material removal, one is a melting and vaporization which I have explained with the help of couple of figures just now because of the spark heat. Chemical reaction is also taking place which is also responsible to some extent to remove the material if proper electrolyte is not selected. Cracks updated by random thermal stresses because temperature is very high in a very localised area. So there is very high temperature gradient and because of this very high temperature gradient thermal cracks are produced in a machine work piece and that leads to the defects in the work piece, if proper machining conditions are not set then mechanical shock, due to cavitation effect is that and this also may lead to some extent the removal of material from the work piece.

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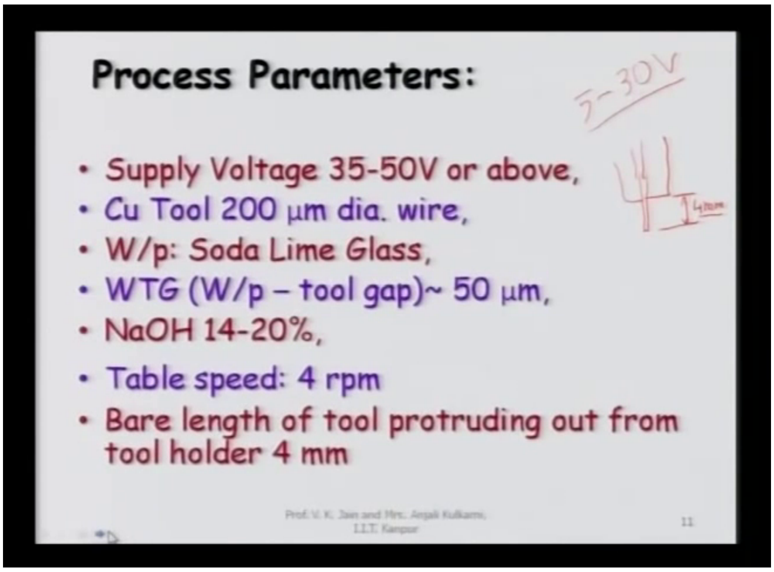

There are various process parameters, the most important process parameter is supply voltage and the value of this is normally kept 35 to 50 volt are even more than that depending whether you are working on micro-machining or you are working on macro-machining. Now you can see here the difference in electrochemical machining normally the voltage kept is 5 to 30 volt but in this particular case where you are creating the spark at the cathode across the hydrogen bubbles you are keeping the voltage 35 to 50 volts or more than that.

Copper tool is normally used in some cases not in all cases and of around 200 micron diameter wire can be used as a tool. Work piece material in this particular case where some experiments were conducted at IIT Kanpur soda lime glass was used as the work piece material, it is electrically non-conducting material. Water to work piece to glass gap, gap between the work piece surface and the tip of the tool that was around 50 micron it can be more than that also as I mentioned in the earlier slide around hundred micron it can be even lower than this depending upon forgot application you are using this particular process that macro or micro-material removal.

Sodium hydroxide has been used as the electrolyte and the concentration was varied from 14 to 20 percent. In micro-machining you can go even lower than this concentration. Table speed because the motion is given to the table so that you can create a certain kind of the features on the work piece, so it is given in the RPM but better way to represent the table speed is in terms of millimetre per second.

Bare length of the tool protruding out from the tool holder is around 4 millimetre because as you will see in the setup there is a tool protruding outside the tool holder this is the tool holder where wire is held, so this length which is protruding outside the tool is shown here as 4 millimetre although it is very large, normally the length of the tool protruding bare length of the tool protruding outside the tool holder should be lower than this otherwise in drilling it will create a tapered hole.

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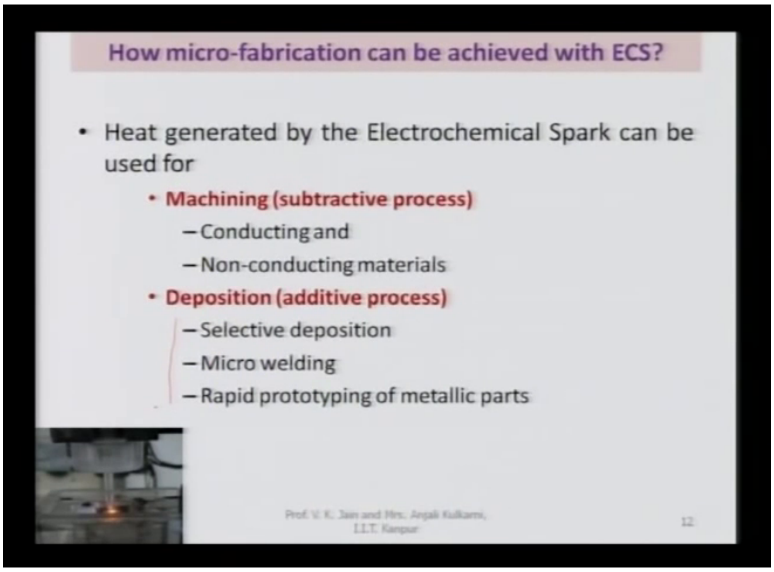

How micro-fabrication can be achieved with electrochemical spark. So far I have been talking about to you about the electrochemical spark used for machining purposes, you can use it other than machining purposes as I mentioned earlier you can use it for the purpose of deposition, you can use it for the purpose of building as well. Heat generated by the electrochemical spark can be used for machining as a subtractive process as I have explained.

Conducting as well as non-conducting materials both can be machined by this particular process then you have to deposition that is the additive process. Selective deposition can be done then you can also use it for Micro welding purposes and people have proposed to use this particular process for rapid prototyping of metallic parts. Although in the deposition process not sufficient progress has been made as long as additive process or versions of additive process like selective deposition, Micro welding and rapid prototyping are concerned but research work is going on in this directions also to make use of it because this process has got certain advantages over the conventional rapid prototyping processes.

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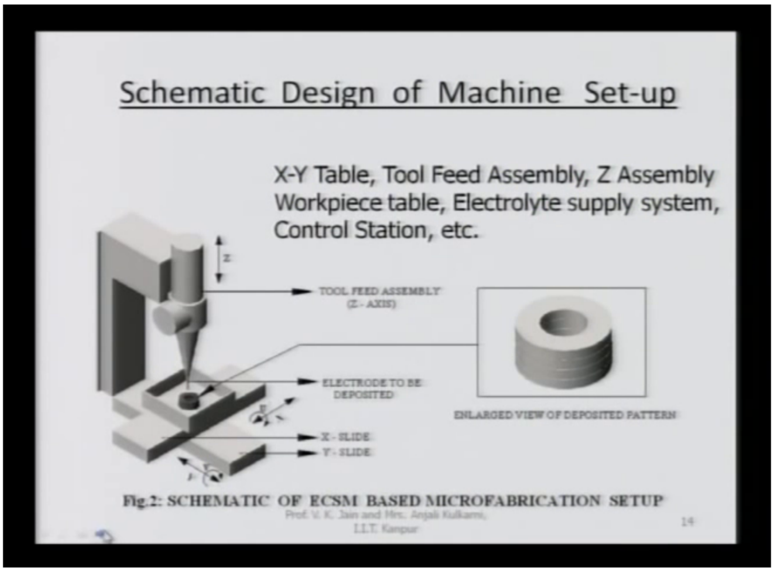

Experimental setup, you can see here this is a schematic design of machine setup which was developed for deposition purposes. Here you can see XY table is there, XY table tool feed assembly is there, z assembly, work piece table, electrolyte supply system, control stations etc. you can see and apart from that it was also designed for rotating the work piece the X direction along the X axis as well as along the y-axis and this setup was developed for micro-fabrication purposes.

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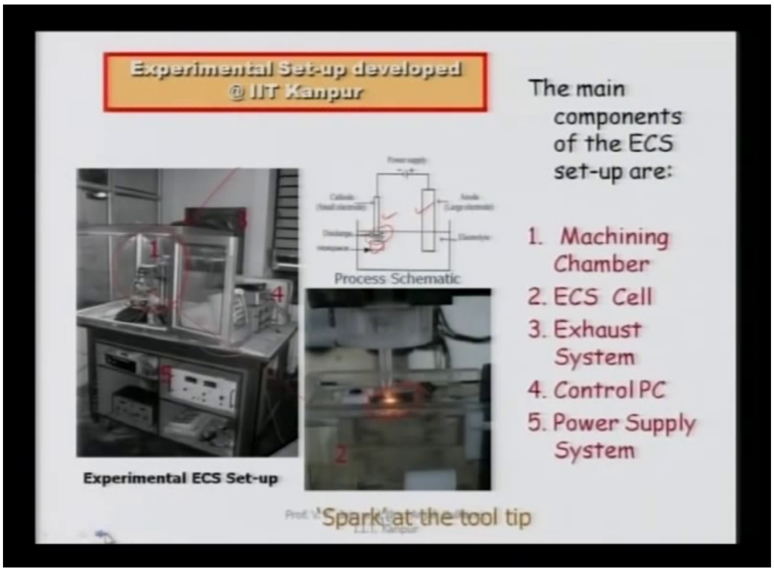

This is the actual photographic view of the setup that has been fabricated at IIT Kanpur. Now working principle is the same as I've already explained, here is anode and here is the cathode and these are the hydrogen bubbles across which the discharge is taking place and near to this discharge you can see the work piece is there and because of the proximity of the work piece to the spark material is removed by melting and vaporization from the work piece.

You can clearly see the spark being created across the cathode and near the cathode rather on across the hydrogen bubble and you can see the shining picture of the spark. The main components of electrochemical spark setup are machining chamber hesitancy over here in the top left hand side picture, ECS cell, exhaust system is there because whatever gases are evolved during electrochemical spark machining those gases should be exhausted outside otherwise they will be harmful for the operator, people standing near the setup as well as the machines that are near to the setup they will get corroded if the exhaust of the fumes is not done properly.

You can see on the backside there is an exhaust system which is not clearly visible and this takes out exhaust fans are there, 2 fans are there which will take out the fumes developed in this machining chamber during electrochemical spark machining. Control of the system is run with the help of the PC and then you have power supply system you have separated power supply for machining and separate our supply for moving XY and Z stepper motors.

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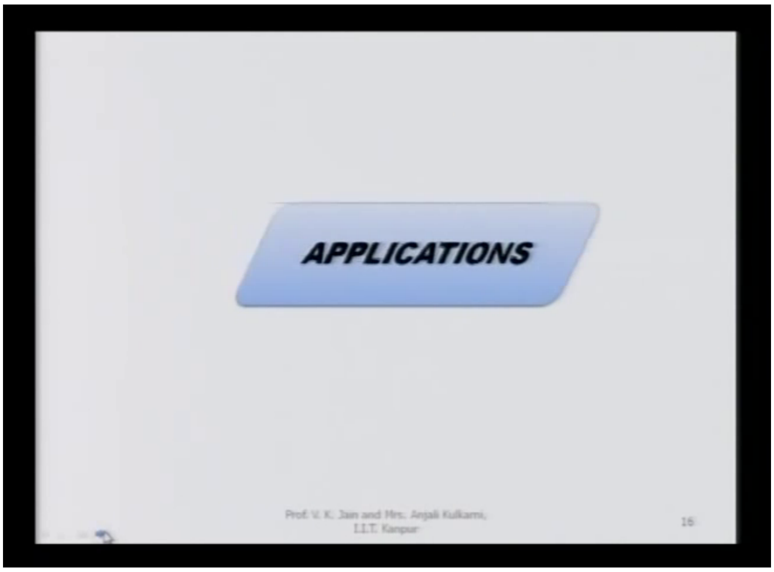

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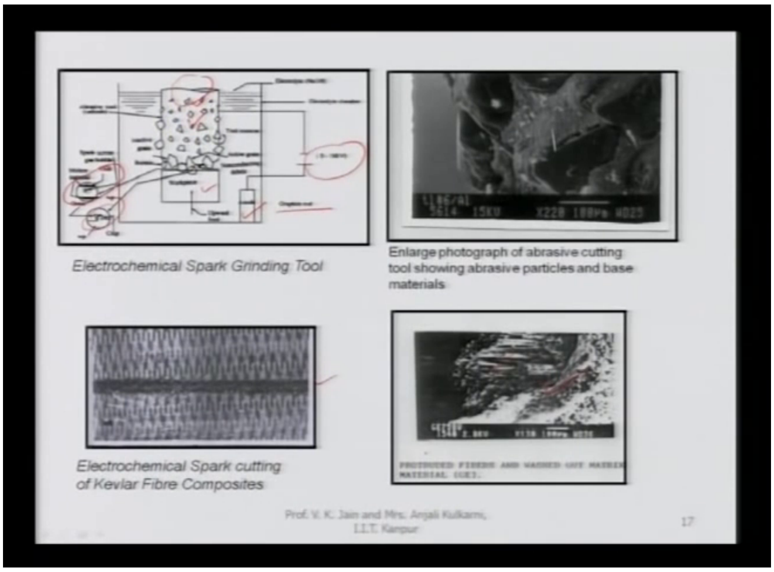

Now there are various applications of this particular process. Now this electrochemical spark grinding process was also developed at IIT Kanpur and you can see the tool instead of plain wire as the tool the copper or brass tool was used which was having abrasive particle embedded on it and these were the Alumina abrasive particle. So when this tool is rotating and electrolytic cell is formed you can see anode is here, cathode is there and they are kept away from each other and then 0 to 150 volts have is being applied across them.

As a result of that hydrogen bubble is formed on the metallic part of the tool. So that metallic part of the tool where hydrogen bubble is forming that sparking takes place and the spark softens the work piece surface and part of the material is removed due to sparking and some part of the material is removed due to the grinding process because abrasive particles are also in contact with the work surface and when you're rotating the tool then this is removing the material due to grinding process or with the help of the abrasive particles which are protruding outside as well as due to the spark.

And you can see here in the picture it is showing the sparking taking place and this is the abrasive particle in contact with the work piece surface. This is the work piece surface over there and here it is clearly written graphite rod is used as the anode because it does not dissolve during electrolytic process. You can see here enlarge photograph of abrasive cutting tool showing abrasive particles and base material, these are the abrasive particles which are in contact with the work piece, enlarged view of this particular left hand side setup is taken.

Electrochemical spark cutting of Kevlar fibre composite this particular process is basically used were electrically non-conducting material and Kevlar fibre composites also electrically non-conducting, so you can see this electrochemical spark machining has been used for cutting the Kevlar fibre as shown over here. Now that when you’re using this particular process for glass fibre composite materials there are certain problems because the melting temperature of softening temperature of the glass is very high compared to the epoxy matrix?

So when sparking takes place near to the work piece surface the epoxy gets eroded or removed and the protrusion of the parts of the fibres remain intact over there. So you really don’t get a good surface when you are using electrochemical spark cutting or machining for glass fibre composite, epoxy composite material. So these are some of the problems which have to be solved before applying it for machining glass fibre epoxy composite materials.

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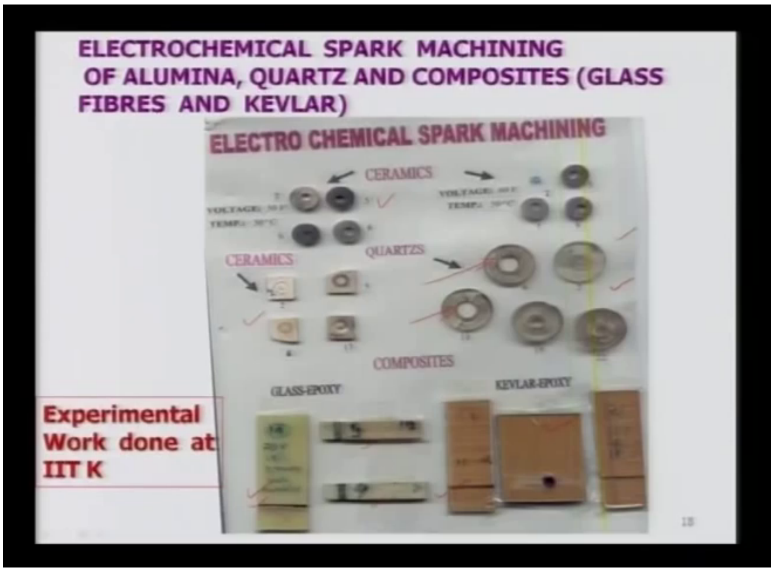

Electrochemical machining of alumina, quartz and composites some of the specimens there were that were machined at IIT Kanpur are shown here in this particular figure. You can see the ceramics which has been machined. Here some conditions are also given 50 volts then here also again you can see other type of the ceramics they have also been machined especially trepanning kind of operations was were tried over here that you can see clearly in this particular case, then quartz was also machined and you can see various components where trepanning was tried and you can see clearly the holes that was drilled by the trepanning operation is and some blind holes also have been made in case of the quartz.

Then you can see here the glass fibre composites, a slot was cut or channel was cut as usable over here and this is the another example of the glass fibre and these are the Kevlar fibre composites where hole drilling and channel cutting have been done with the help of electrochemical spark machining process. So what does it mean? That it can be successfully used for creating various kinds of the features on electrically non-conducting material like ceramics, quartz, glass epoxy composites or Kevlar epoxy composite’s.

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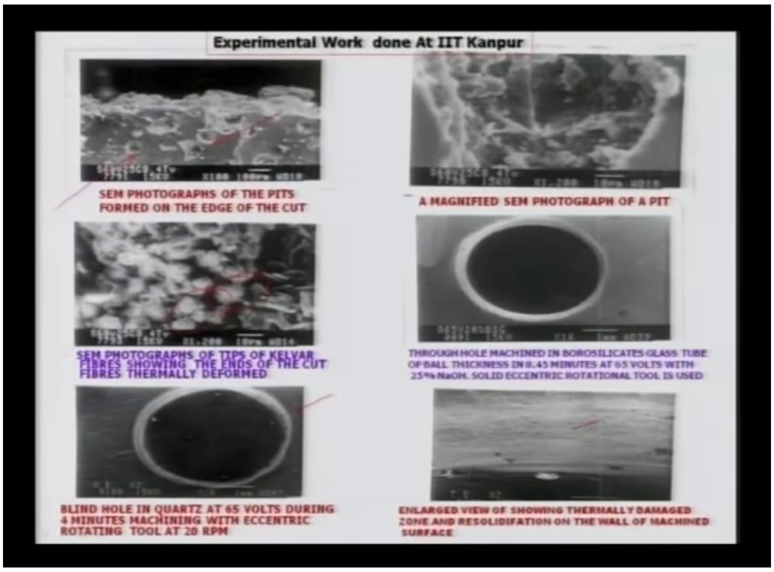

SEM photographs of the pit’s formed on the edge of the tool. Now you can see because as I have mentioned earlier that sparking is taking place between the or across the hydrogen bubble and these hydrogen bubbles are evolved at the tool on the metallic part of the tool not the abrasive part of the tool. So you can clearly see that metal that is being removed is in the form of circular pit and this is due to the sparking taking place on the tool.

SEM photographs of the tip of Kevlar fibre is showing the ends of the cut fibre thermally deformed. As I showed you in the earlier slide that glass fibre epoxy composites are being machined using electrochemical spark machining. Now what happens to the glass fibres at the tip you can see that melting or softening of the glass fibres was taking place and you can see the tip which are not sharp rather they are rounded because the soften material or molten material has re-solified over there itself. So this clearly indicates the fact that this is a thermal process taking place.

Now blind hole in quartz at 65 volts doing 4minutes machining with eccentric rotating tool at 20 rpm you can see the cleanliness with which the blind hole has been made in the quartz. Now a magnified SEM photograph of a pit and that indicates that the material is removed and it also gives some idea, what kind of heat source it is, to me it looks that it is a Gaussian heat source and more amount of material is removed from the centre and less amount as removed from the edges.

This is another example of through hole machine in borosilicate glass tube of wall thickness in 8.45 minutes at 65 volts with 25 percent NaOH as the electrolyte, solid eccentric rotational tool is used, so this has been cut as a hole. An enlarged view showing thermally damage zone and re-solidification on the wall of machined surface you can clearly see the damage that has taken place on the sides or on the top surface of the work piece due to the heat source.

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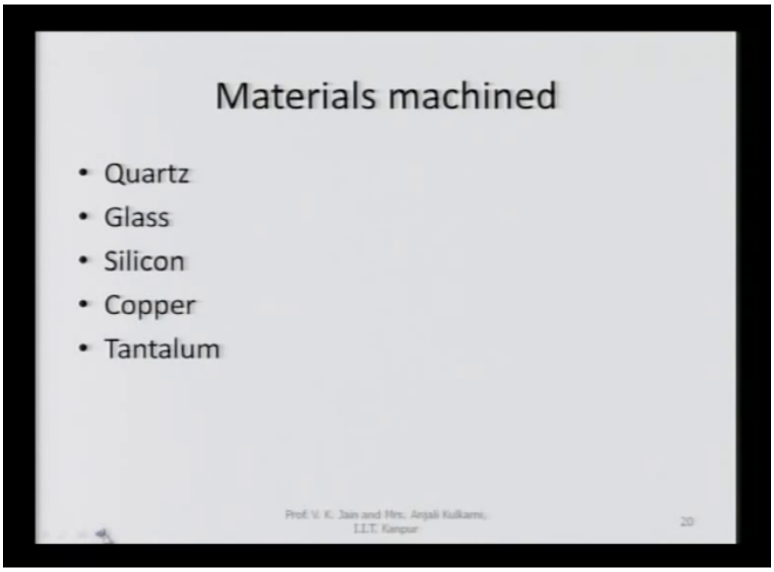

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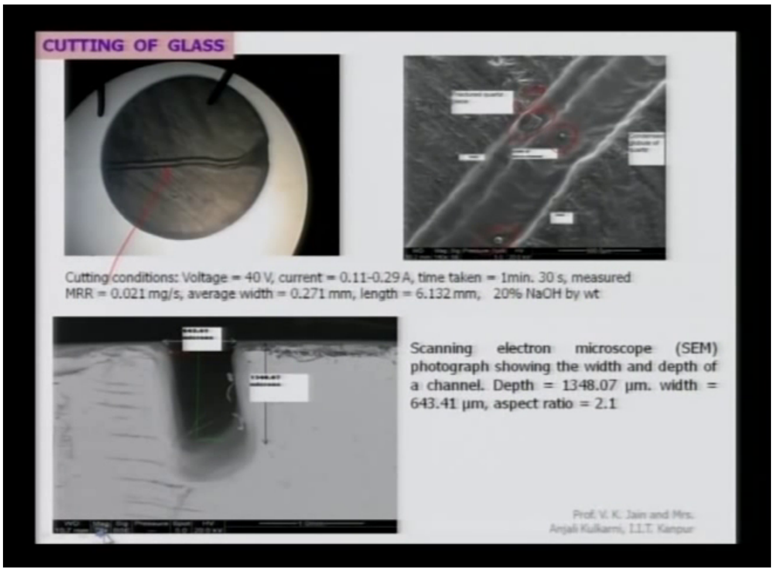

So we have been able to machine quartz, glass, silicon, copper also and Tantalum as well. So some examples will be shown to you about the cutting of glass, you can see here a micro-channel this is the enlarged view of the micro-channel formed on the glass. This is enlarged view of the micro-channel and you can see some of the global shown over here but some of the non-globular form material is also shown that means due to the micro-crack some material got removed from the parent material and that is what is shown over there but at most of the places you will find globular form of the material because whatever is the molten material or soften material that gets solidified then naturally it is going to be in the form of a sphere. This is the another example of a micro-channel formed with the help of electrochemical spark machining process and you can see the size width of the channel is 643 micron and length is 1348 micron, so it is around aspect ratio as 2.

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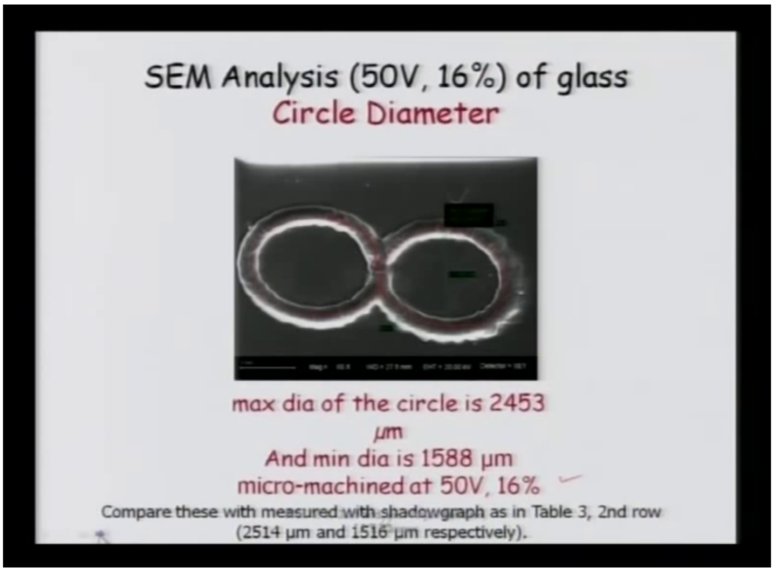

Now this is very peculiar very interesting figure that has been made by IIT Kanpur by Anjali Kulkarni during her Ph.D. work. The complicated channel has been created in the shape of 8 as you can see over here and this is quite accurate as long as width is concerned and uniformity of the diameter is concerned and the conditions are at 50 volts this was machined.

Now you can see here the enlarged view of the channel. Now this is a thermal process and you can see lot of cracks are formed on the machine surface and these kinds of the cracks are not acceptable in real-life products. So one has to optimise the parameter, so that the cracks etc are eliminated during formation of the channel or groove or the hole.

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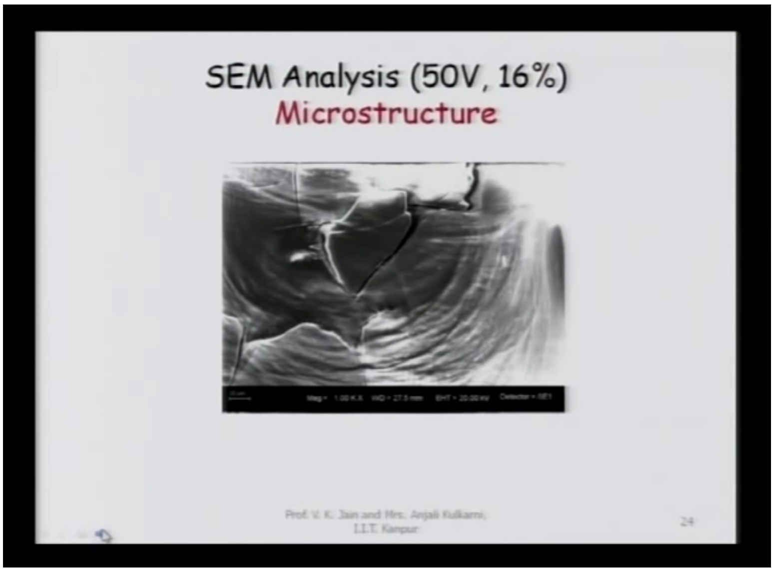

You can see further enlarged view then clearly you can see the cracking of the top surface or machined surface.

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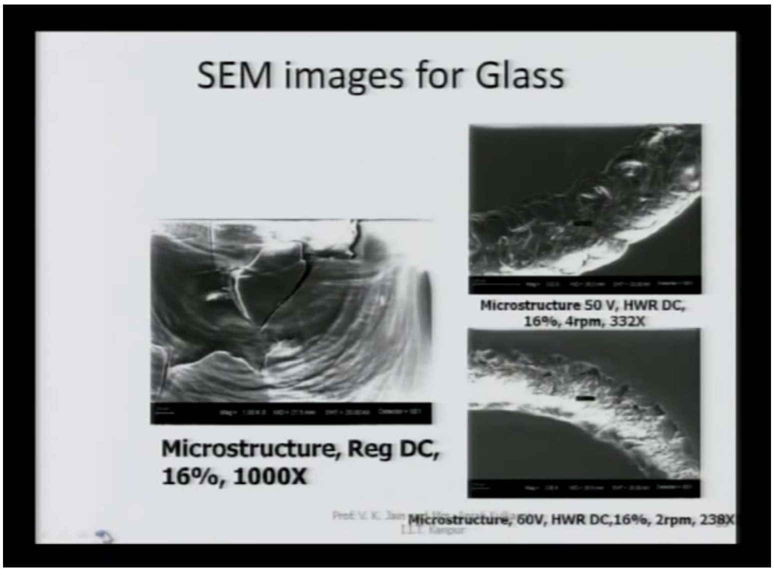

Again further view of the glass, micro-channel formed and cracking taking place on the machine surface, this is another view.

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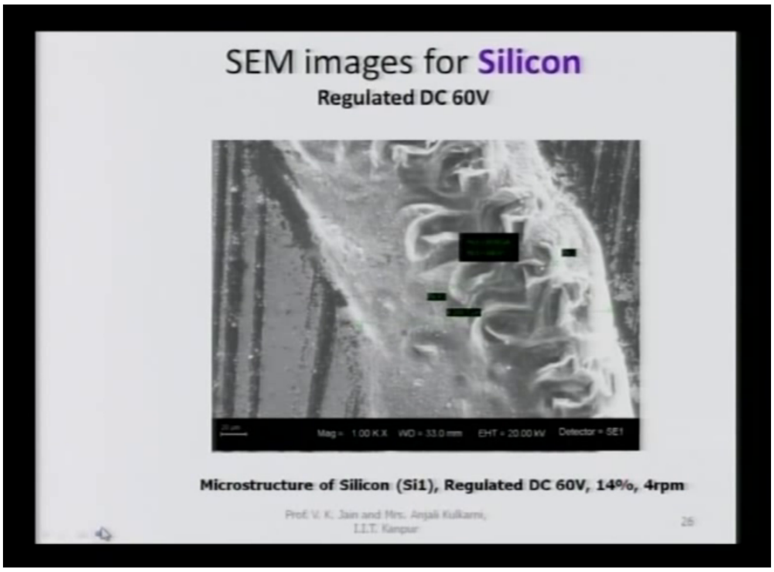

Now here is the silicon, you can clearly see the structural difference between the class channel and the silicon channel. Here those kinds of the cracks are not observed in case of silicon channel as we have observed in the case of glass and this is basically due to the difference in thermal properties, mechanical properties and physical properties of these 2 materials that is silicon and the glass.

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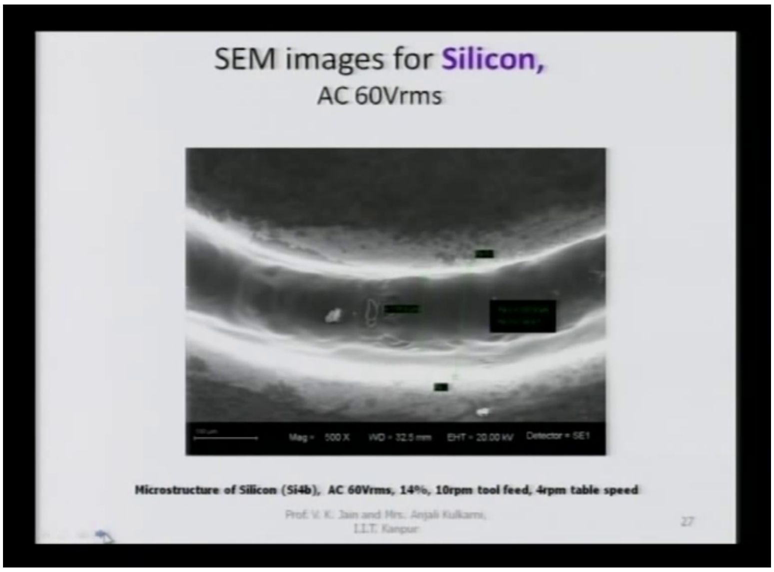

Now again silicon you can see the cleanliness of the channel formed in the silicon work piece. However there are some debris that are also seen in this particular case as you can see here within the circle and all these channels have been formed with the help of electrochemical spark machining process as I've explained to you.

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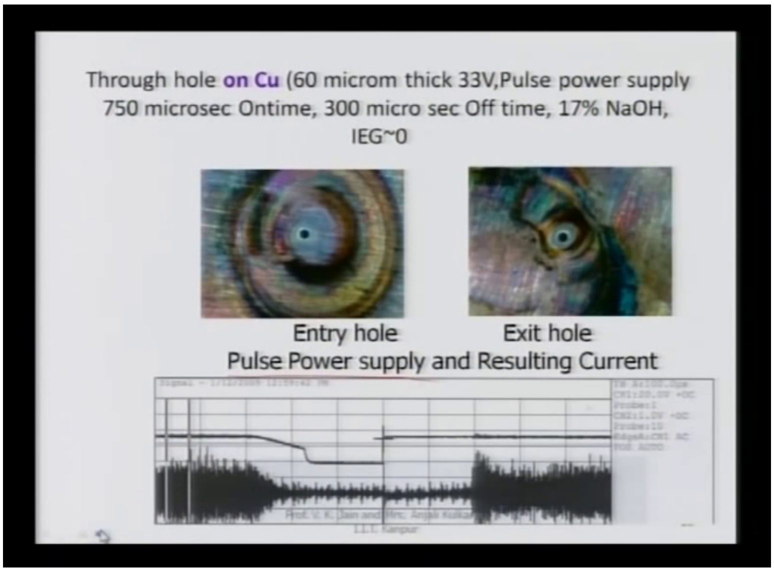

Then metallic pieces we have also machined and the holes were drilled micro-holes were drilled and you can see when you are drilling the hole the size of the hole at the entry and size of the hole at the exit will be different and that is what we have tried to show here this is the copper and this is a entry side hole and this is the exit side hole and we had used here pulse power supply and you can see here pulse power supply in resulting current that we have observed during the process.

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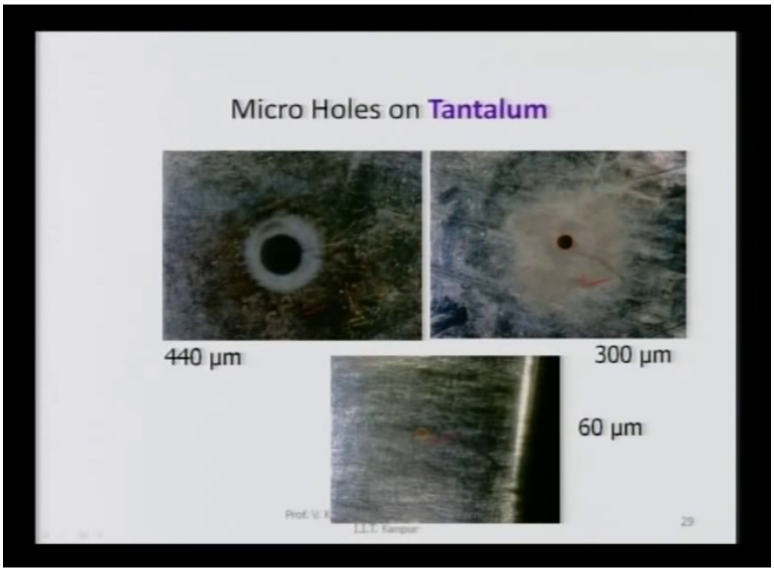

Then Tantalum material was used as the work piece and using the electro chemical spark machining process we have drilled the hole on the Tantalum and you can see the roundness of the hole in all the 3 cases this is very small holes 60 micron, this is the hundred micron and this is 440 micron holes drilled with electrochemical spark drilling process and these are the electrically conducting materials.

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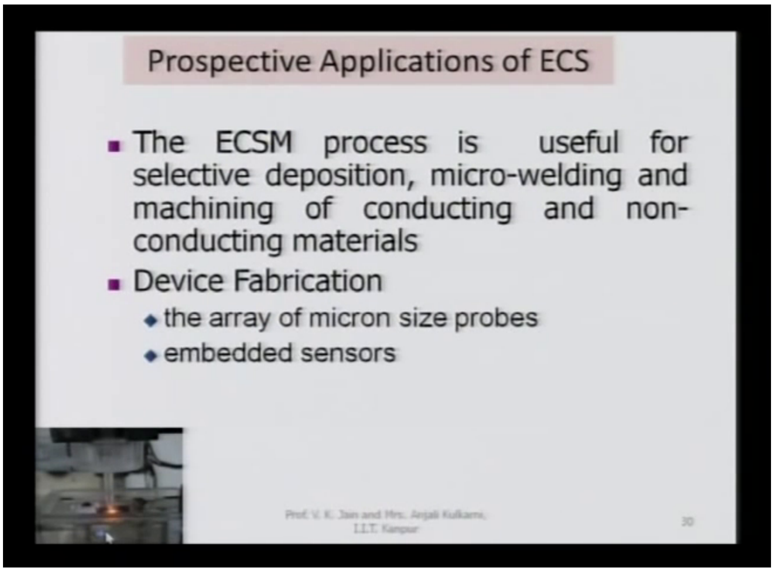

So we have been able to make use of this particular process for electrically conducting materials as well as electrically non-conducting materials. However this process was basically developed for electrically non-conducting materials. So the ECSM process is useful for selective deposition, micro-welding and machining of conducting and non-conducting materials. Device fabrication can be done with the help of this process, the array micron size probes and embedded sensors.

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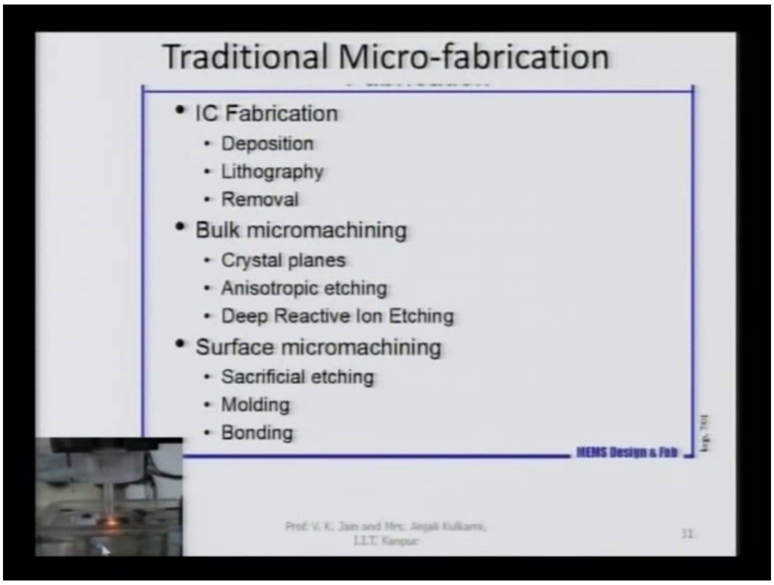

There are various traditional micro-fabrication processes like IC fabrication, bulk micro-machining and surface micro-machining.

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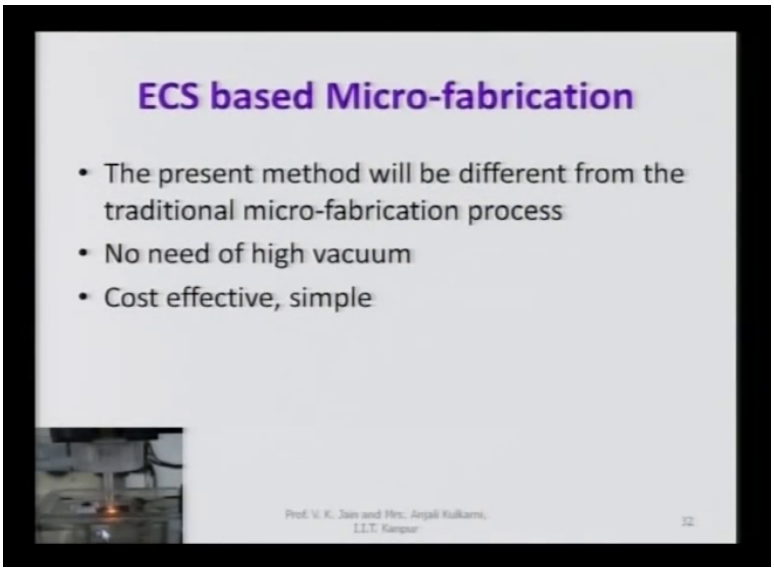

ECS based micro-fabrication, the present will be different from the traditional micro-fabrication process. There is no need of high vacuum that you normally use whether it is the iron beam machining or deposition or electron beam machining or deposition or other processes. It is cost-effective and simple.

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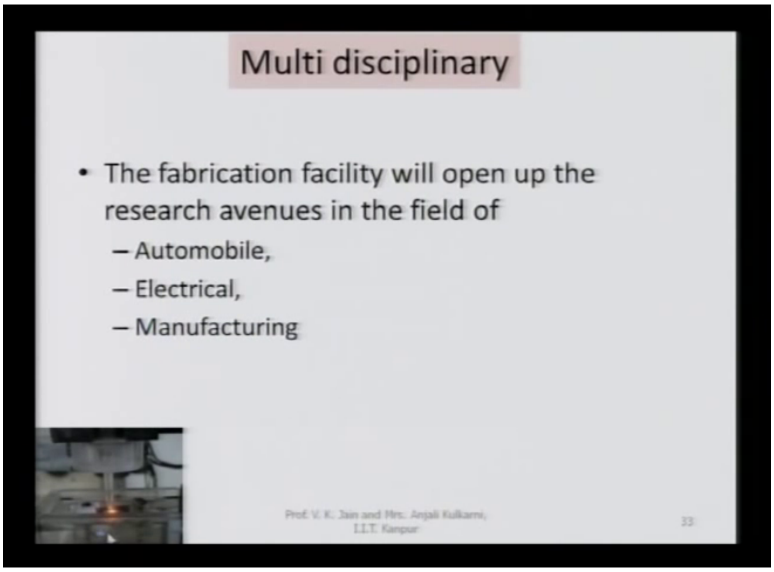

Definitely it is multidisciplinary; the fabrication facility will open up the research avenues in the field of auto mobile, electrical, manufacturing and similar other areas.

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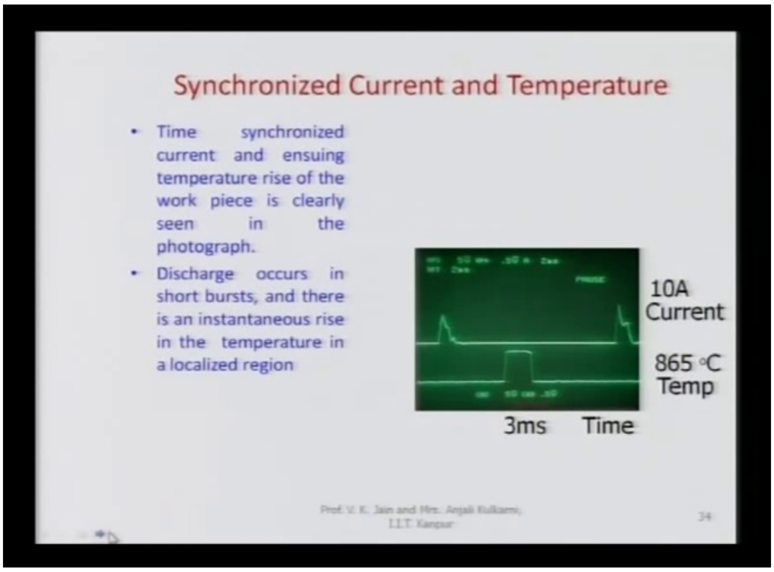

You can see some of the basic research that was conducted at IIT Kanpur by Anjali Kulkarni is that the recording of the current during electrochemical spark machining process and simultaneously measurement of the temperature variation with time.

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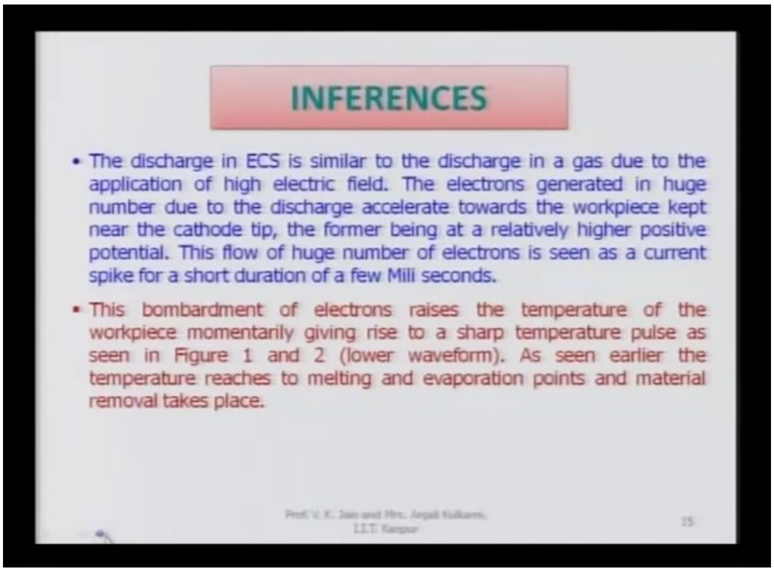

So we can draw following inferences that the discharge in electrochemical spark is similar to the discharge in a gas due to the application of high electric field. The electrons generated in huge number due to the discharge accelerate towards the work piece kept near the cathode tip, the former being at a relatively higher positive potential. This flow of huge number of electrons is seen as a current spike for a short duration of a few milliseconds.

This bombardment of electrodes this is the temperature of the work piece momentarily giving rise to a sharp temperature pulse as seen in figure in the earlier slide. As seen earlier the temperature reaches to melting and evaporation points and material removal takes place due to the melting as well as evaporation.

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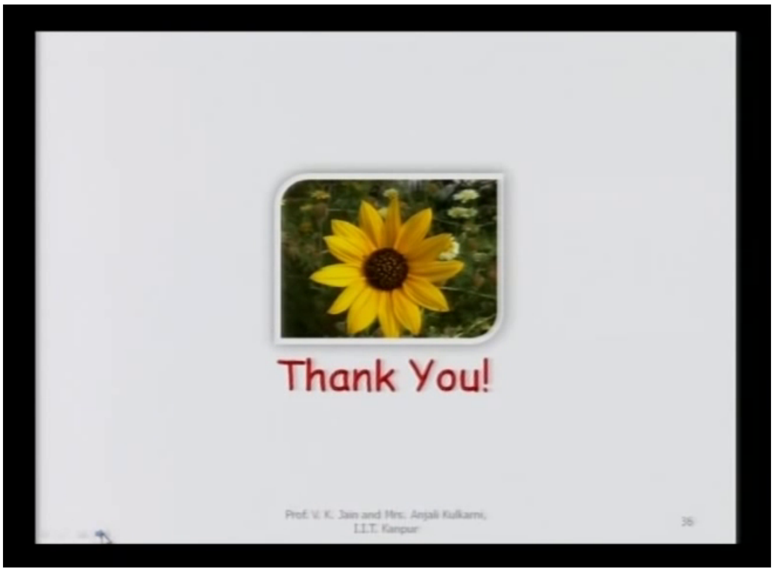

Thank you very much. Now Mrs Anjali Kulkarni is going to explain you the experimental setup, some applications of the setup and how various elements of the setup had been fabricated, thank you very much.

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Good morning you are welcome to the Manufacturing science lab and we will be shooting about the experimental setup that is a part of series of professor VK Jain's lectures on advanced machining processes. Here you will be introduced with the electrochemical machining processes in general and electrochemical spark machining process in particular.

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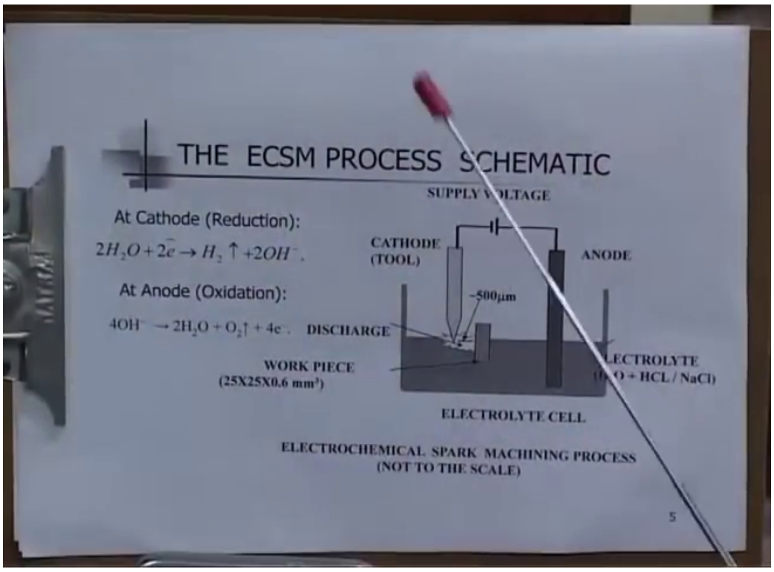

This is a schematic of the electrolyte cell, there are 2 electrodes, one is anode other is cathode and the work piece which is a separate entity is placed near by the cathode tool, the cell is filled with the electrolyte, normally we use diluted solution of HCL or sodium hydroxide and in ECSM particular unlike ECM the tool sizes are different means they are grossly different in size, anode is of larger size and cathode is of smaller size this ensures the sparking at the tooltip and between the interface of the tooltip and the electrolyte.

A supply is given, when the supply is given in this polarity negative 2 cathode and positive to anode then 2 electrochemical actions take place these are called Redox. At cathode you see the reduction action by water molecules combine with the electrons and they evolve H2 gas near the cathode and at anode the oxygen gas liberates.

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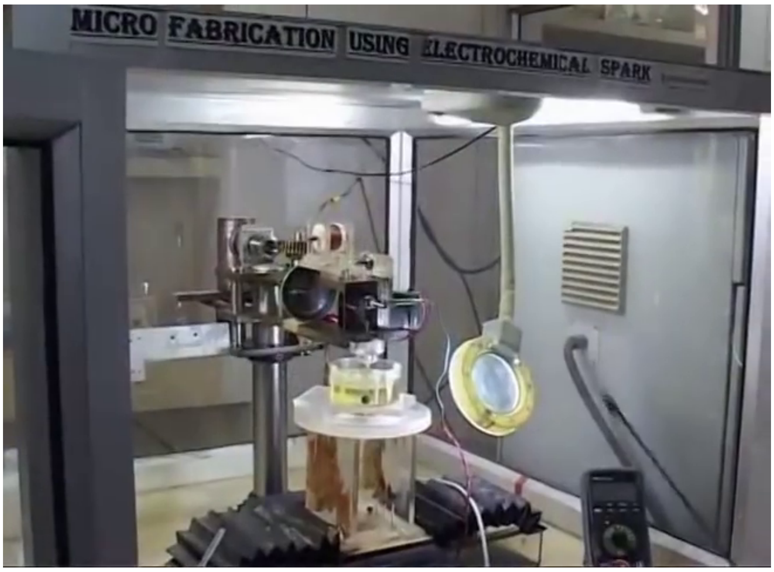

This is the setup which we have developed at IIT Kanpur, this is about a micro-fabrication using the electrochemical spark, this process or this project is sponsored by DST Department of science and technology. This is the machining chamber of the electro chemical spark machine used for micro-fabrication. This is the XY stage which are motorised using stepper motors and guide tray is for the travel, this has total travel of 100 MM with an accuracy of 1 micro-meter per step.

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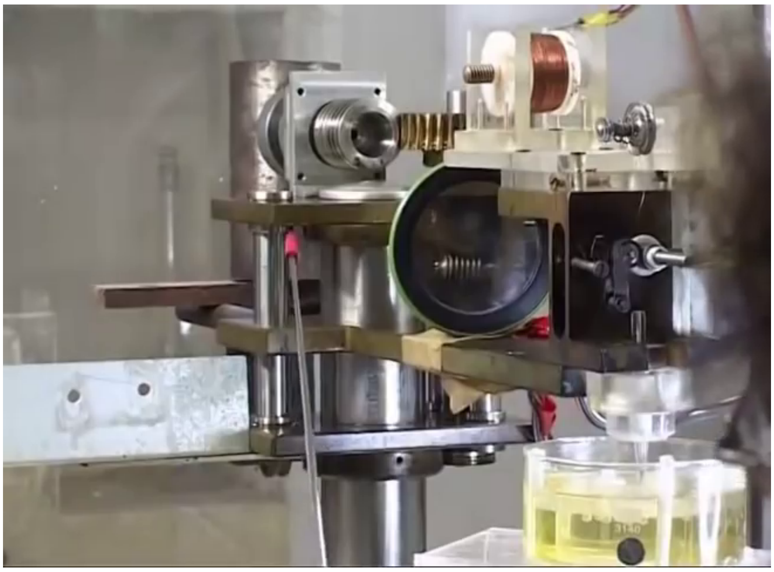

The XY are both similar in size, Bellers are used to protect them from the electrolyte environment. This is the Z axis the total assembly is made of aluminium and brass to avoid the corrosion due to electrolyte. A separate stepper motor is used to write this up and down, 1 is to 38 gear ratio is used to transmit the power. Again this motor is interface to the control station. On the Z axis we are saying this is the tool feed assembly which is mounted on the Z axis this has got separate stepper motor.

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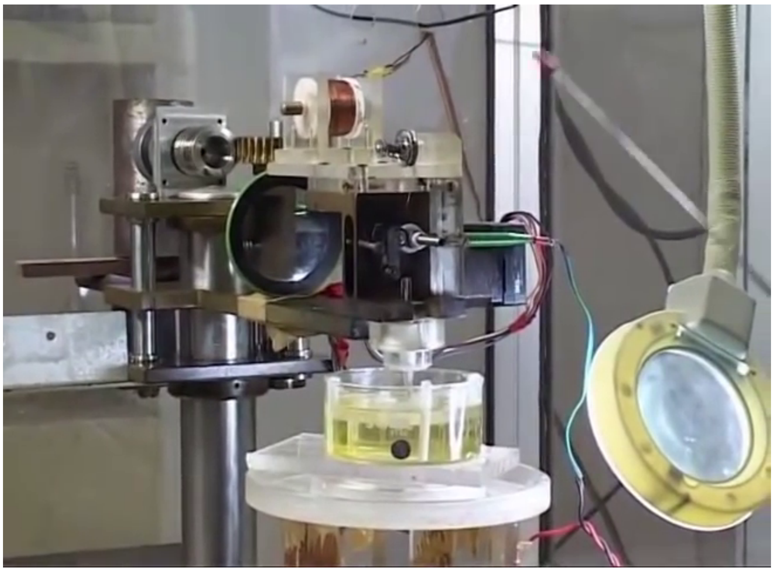

This again is interfaced with the control station using control card National instruments control card. So we can activate X Y Z Up down and tool feed. A provision is also made to have the work piece rotation and tilt in work piece which right now is dismantled but that again is interfaced, so that we have 6 degrees of freedom machine and here this machine though it is fabricated for spark machining process with the change in electrolyte and with the change in power supply and the scheme this same can be used for electrochemical machining, electro discharge machining by using kerosene as a dielectric in the electrolyte cell and for electrochemical spark machining.

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This is the control station and all the 4 motors those are interfaced to a National instruments motion control card that is a stepper motor control card and here you can have a look at the program, with these programs we can move the XY stage the Z assembly or the tool feed. We can change the RPM or the velocity and we can give number of pulses to move in a particular distance.

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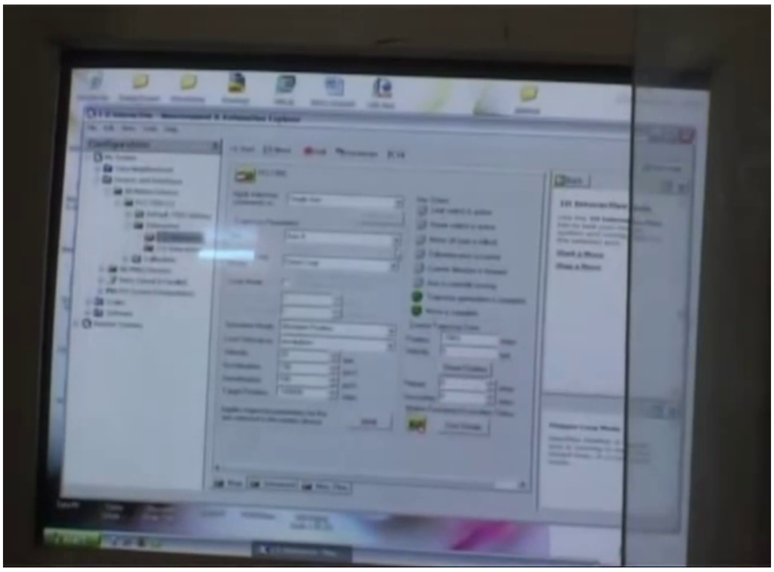

I will show you how it is controlled; I will show you the motion of each and every axis wire this control card. One can see right now this is Z motion, I am programming it, so here is the single axis motion mode, axis 8 is configured to the Z axis assembly, we are using open loop control there is no feedback from the stepper motor as such, the velocity and setting it has to be 20 RPM.

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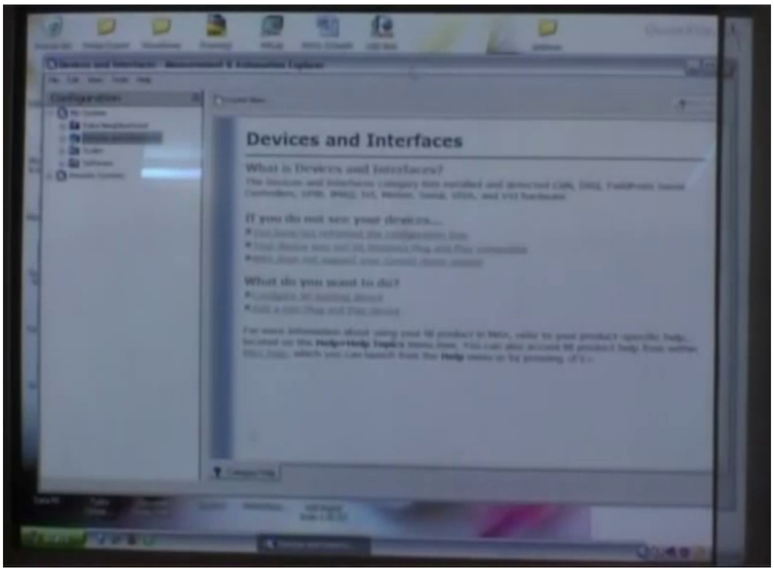

This is a control program based on Lab view platform, Lab view is software, description is as laboratory Virtual instrumentation engineering work bench is the acronym as lab view. Here we have used stepper motor card that is Ni7358 which has got 8 axis meaning we can control 8 motors. Here we are using 6 motors and all those 6 motors are different types of stepper motors those are all interfaced to this control card.

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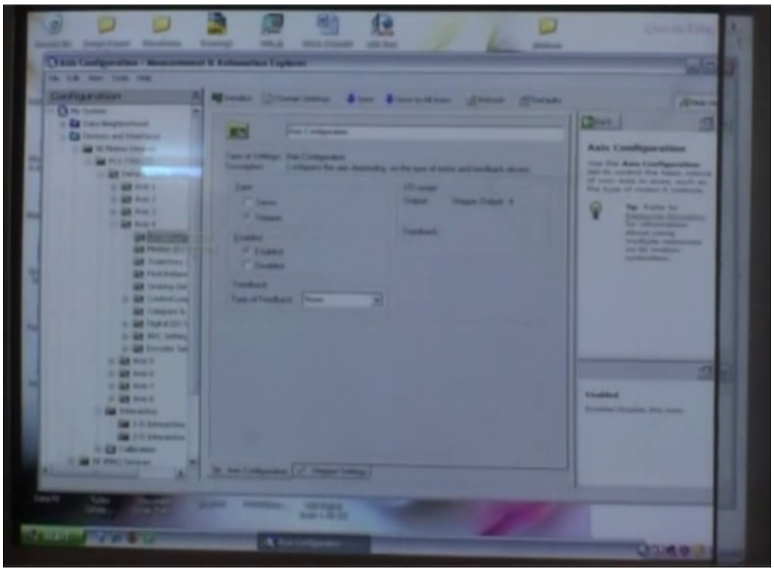

Here one can see this is the configuration of the card and here one can see the devices, hardware's interfaces. So this gives you these default settings for axis 1, 2, 3 to 8. We have axis 4 and 5 connected to encodes are enabled this is a feedback is not there this is a stepper motor. So likewise we have configured for all the axis, axis 5 is also configured and there are different default settings.

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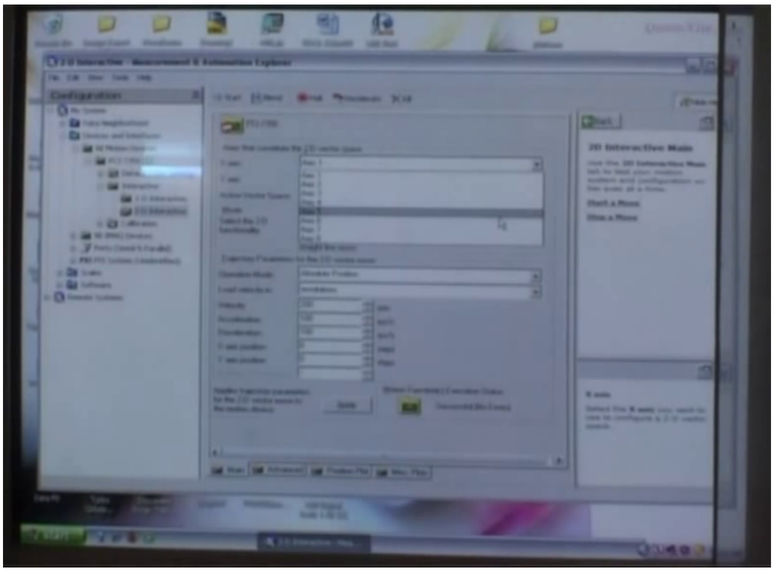

We can move axis 4 in the interactive mode. So I will go to, now to the interactive is 1d car I can go to 2d interface mode. Here I will change the definition as axis 5 is configured to do X axis and axis 6 is configured to the Y axis. So in this mode if I remove axis 5 and axis 6 both together. In this 2d interactive mode we can have different types of contouring actions, so we can go to circular mode which we have used in our work on making the micro-channels in the shape of 8.

So here what we are doing is that, axis 5 and 6 are configured in the circular mode, we can change the velocity we will go to small velocity, this velocity is in RPM this results in one RPM of X axis results in 5.55 micro-meters per second. I will show you how the control station gives me the contouring possibility.

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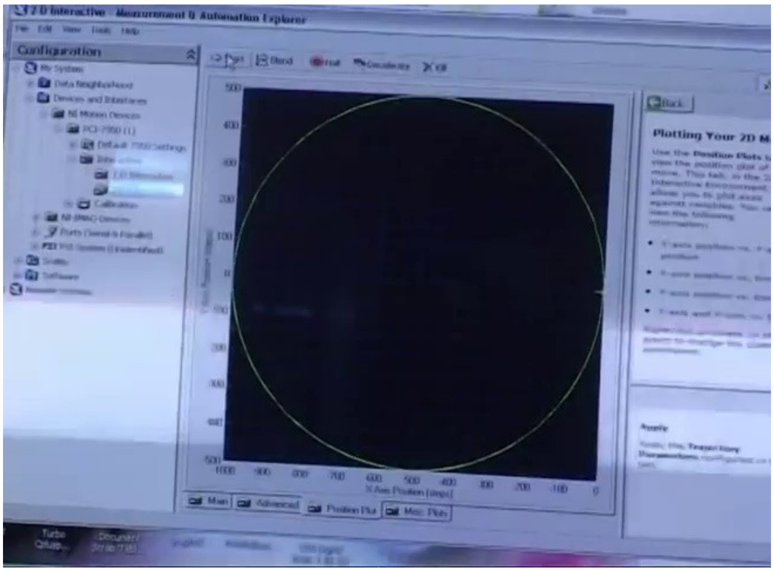

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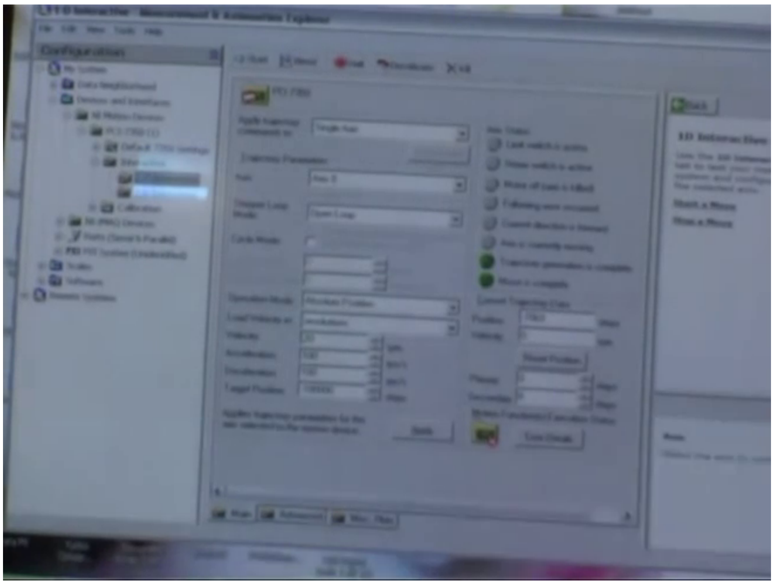

I'm starting the motor configuration has taken place. So this same will be followed in the XY stage and we can have a machining in the circular nature. So this is about the contouring function of the control station, I'm going again to 1d interactive mode here I can show you working of each single axis. So I'm setting now to X axis and we will see the resultant in the XY stable motion.

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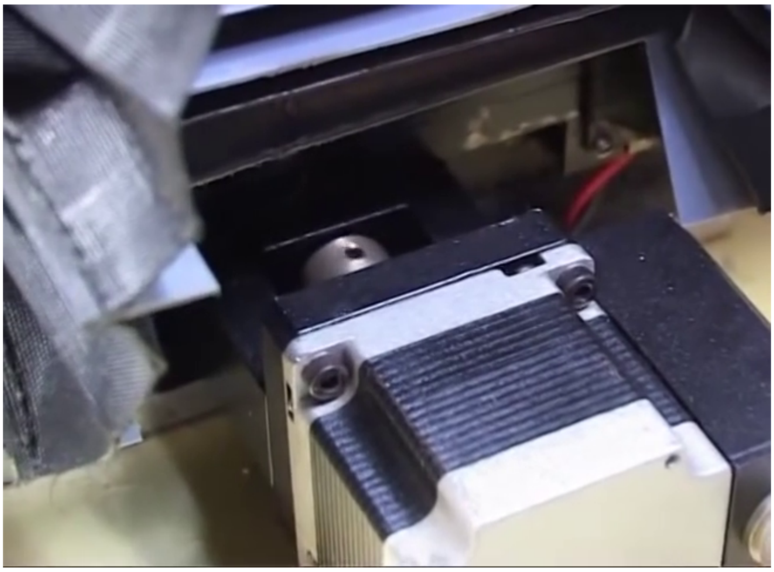

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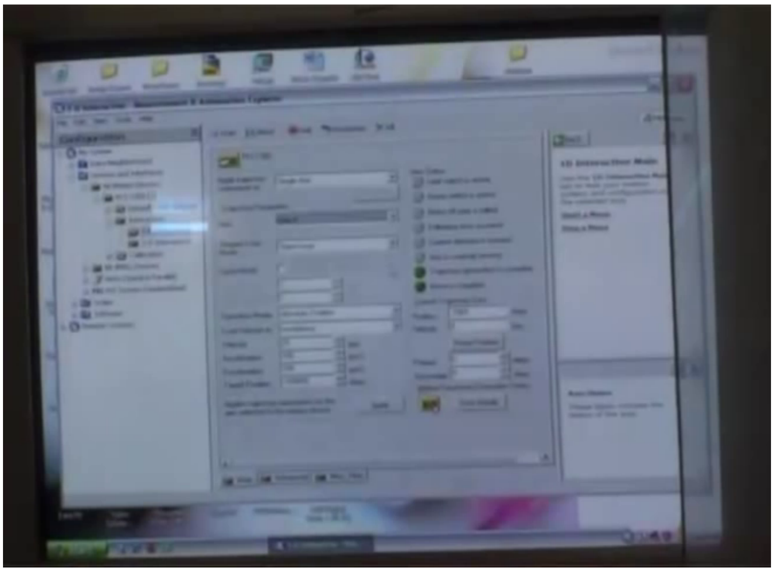

Now one can see the Y axis is rotating in the counter clockwise direction and though the actual position cannot be seen or hear, the stage is advancing forward. I can show you now the change in direction. Now you see the motor is moving in the opposite direction. Now I'm showing you the motion of Z axis, I have configured here for axis is 8 which is connected to Z axis, the velocity I have maintained is 20 RPM which will correspond roughly to 1.6 micro-meters per second and the negative direction will show it going upward.

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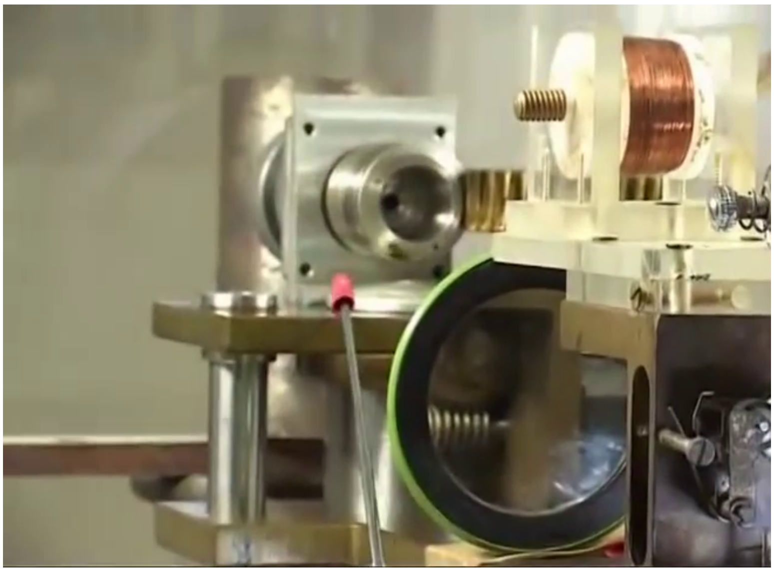

As you can see over that, so this is the z-axis, so which is taking the Z assembly up by 1.6 micro-meters per second rate. I will show you the opposite direction motion by configuring the position and changing this position sign.

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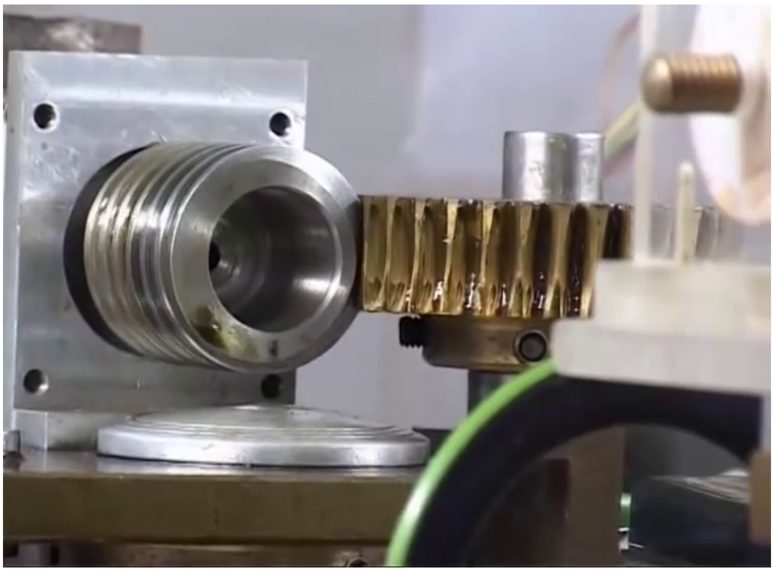

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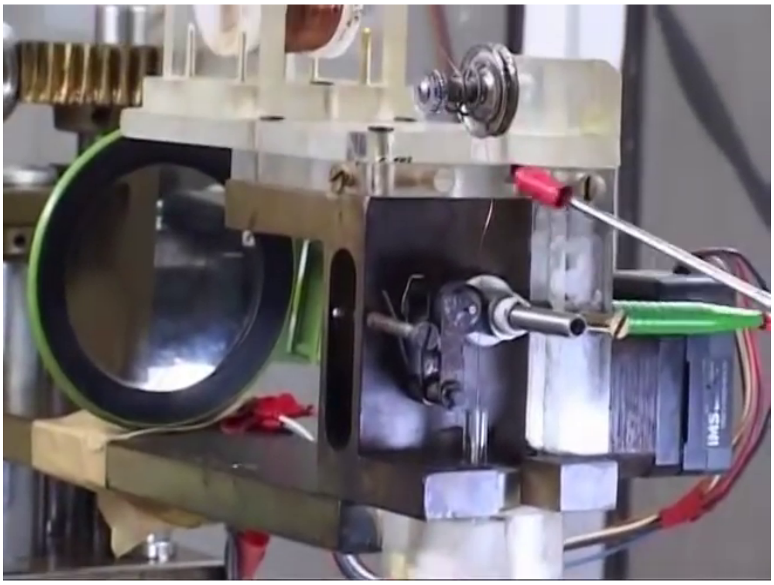

One can see that the motor is moving in the opposite direction and that z-axis is taking this Z assembly at the lower position. The accuracy of this is 50 micrometres per pulse, so we can set the gap between the tool and the work piece by taking this Z axis assembly and by adjusting the tool feed also. Now in the control program I have configured for axis 2 which is connected to the tool feed.

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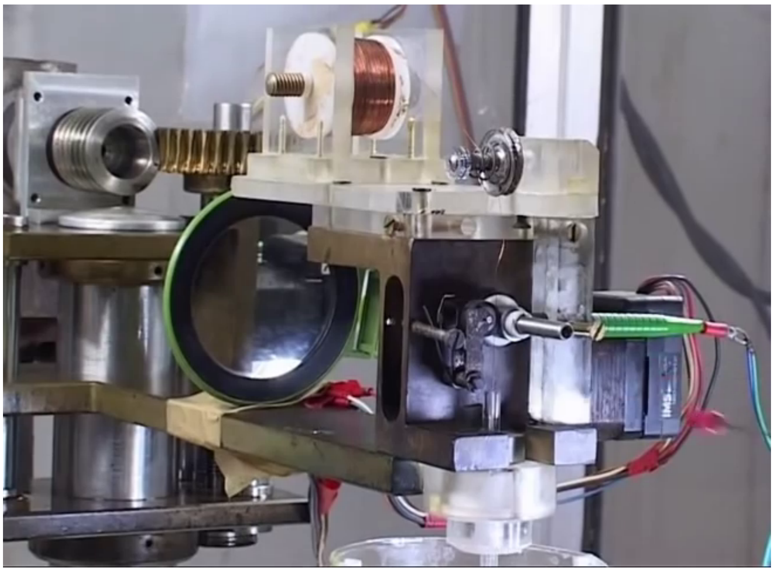

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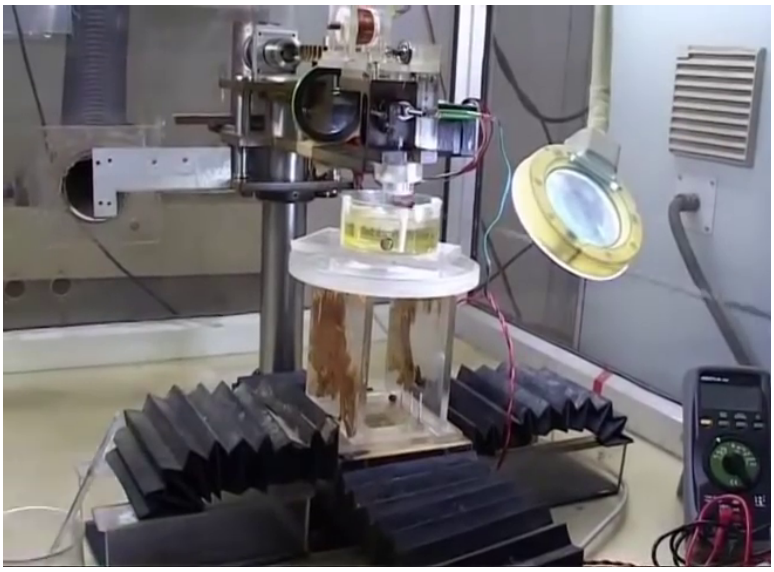

So one can see over here that this motor is moving and the result can be seen in this mirror over here. So this was how the XY stage, z-axis and tool feed they work while the control station. Here one can see the electrolyte fumes while the machining is going on electrolyte fumes the come out and those need to be taken out from the set up to avoid the corrosion.

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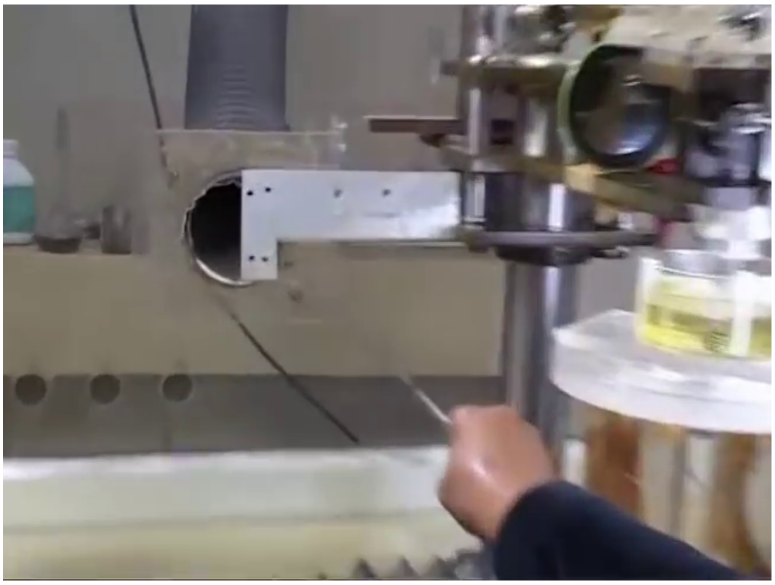

Here one can see the whole switches connected this takes the fume away and there is a exhaust fan over there that quickly removes the fumes. So after seeing the operation of how these stages move we will now set up the experiment.

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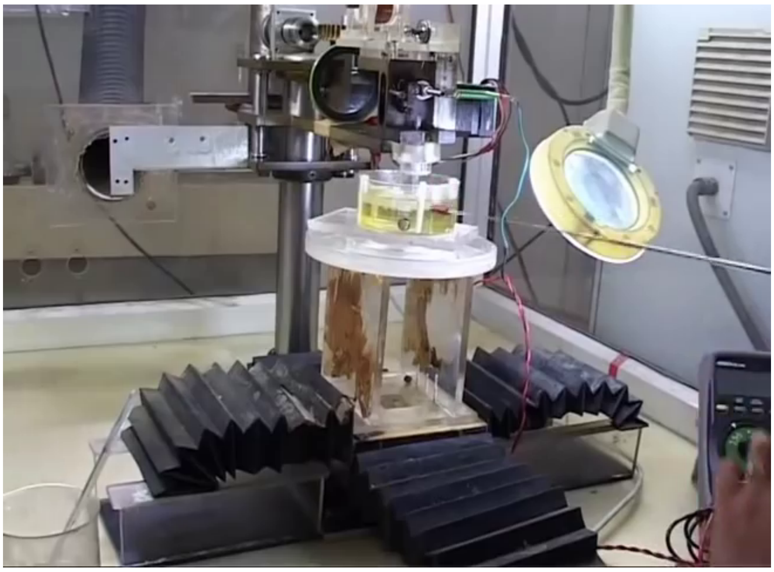

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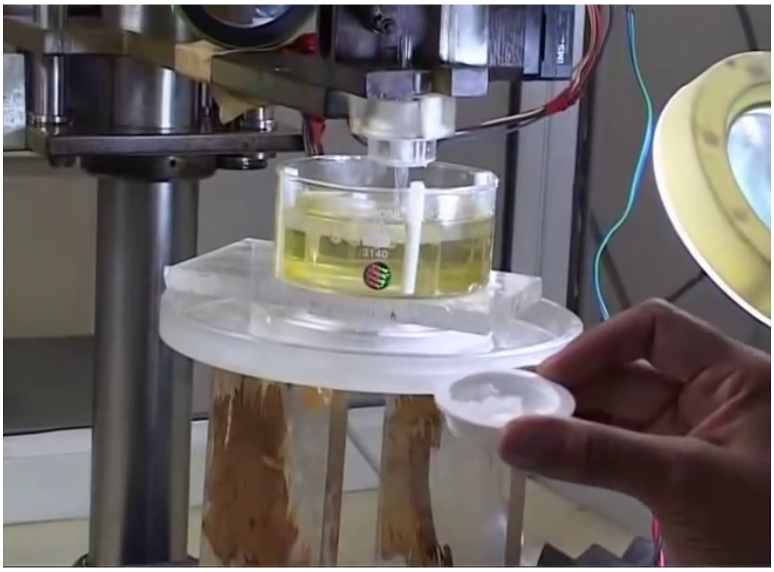

Here on you see here the electrolyte cell is there which is comprised of a beaker, this is filled with 14 percent of NaOH, this NaOH pellets look like this, this we weigh on the electronic weighing machine, so for making 14 percent NaOH solution we have to resolve 14 gram of NaOH pellets hundred gram of water. So this is how the solution is prepared. We fill the bigger with the solution, one can see here the work piece mounting stage this is the tool wire coming out and one glass tube is provided to avoid the stray current effects.

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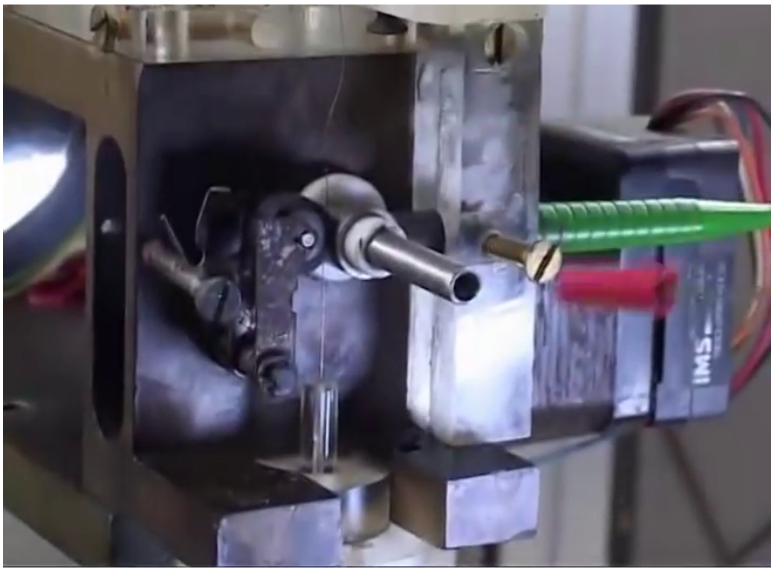

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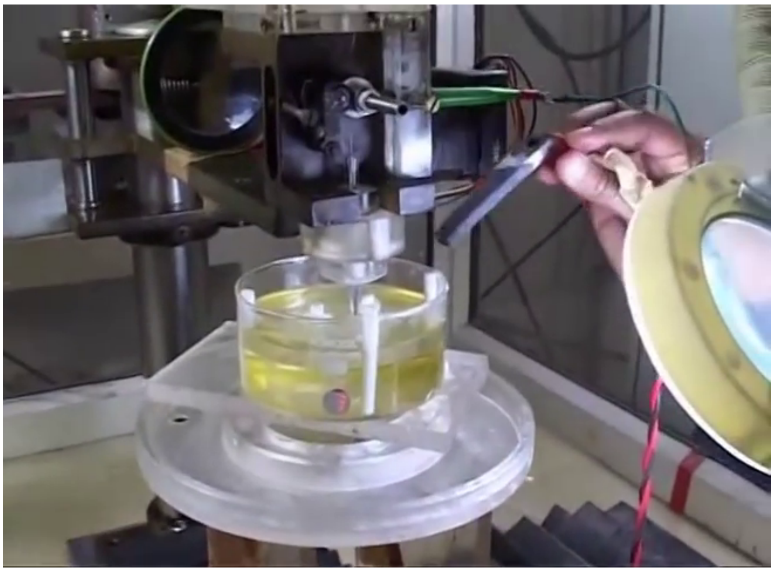

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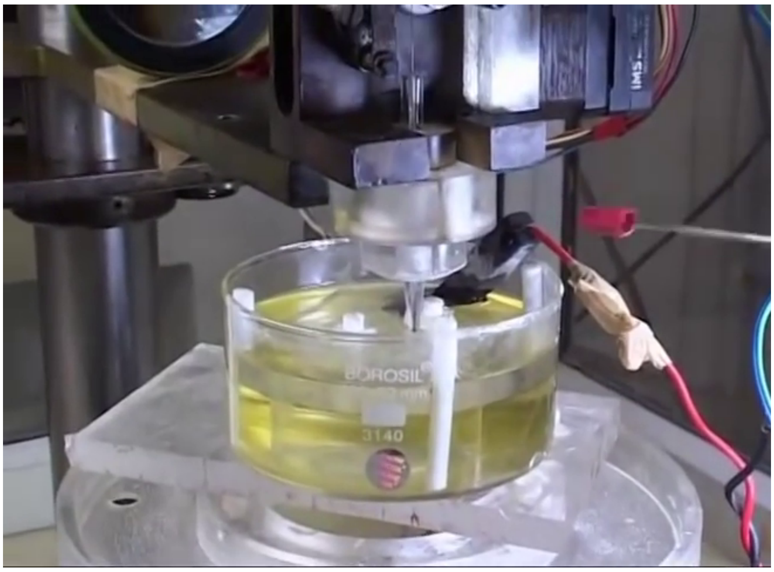

There are 2 electrodes this is cathode passing through this glass tube and protruding out here. This glass tube provides the protection from having the stray current effects. This is the anode which is a graphite anode whose resolution is very less, this is inserted in the electrolyte a gap of 3 centimetre between the cathode and anode electrode is maintained then a glass work piece in the form of a cover sleeve is mounted which is not very visible and the electrolyte level on the top of the work piece is maintained around 1mm the level we ensure with the measurement we have used a small piece of scale and we see the level over there.

Then we maintain the gap between the tool and the work surface with the help of the z axis assembly that makes the course arrangements and for find arrangements we use tool feed mechanism. So in our experiments we maintain a gap of around 50 micrometres between the work piece and the tool wire. We have different kinds of standard materials of standard thickness we used those to see the gap.

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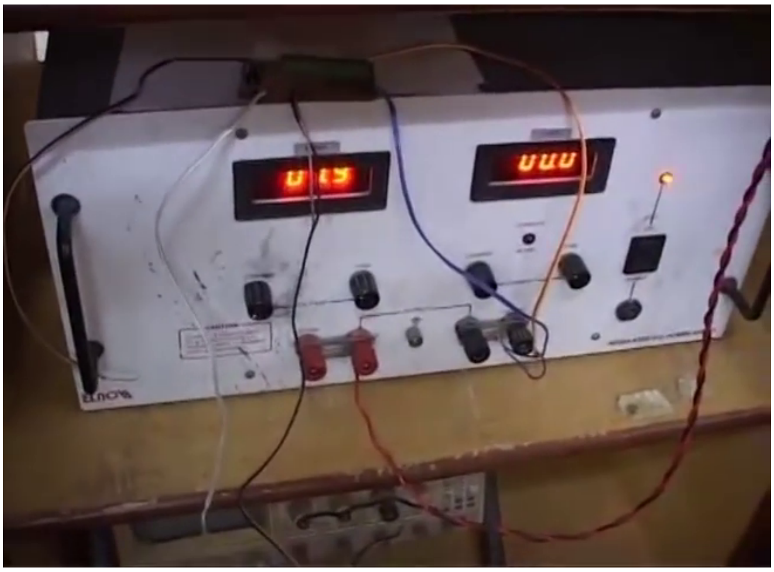

Here now the gap is less than 60 micro-meters, the power supply to this cell is given with this unit, this is a DC power supply unit, this changes from 0 to 60 volts and its current capability is of 15 amperes, these are the wires which are connected to the electrodes. I will show you now by connecting the DC supply how the spark occurs and the tooltip I am varying the voltage slowly and gradually.

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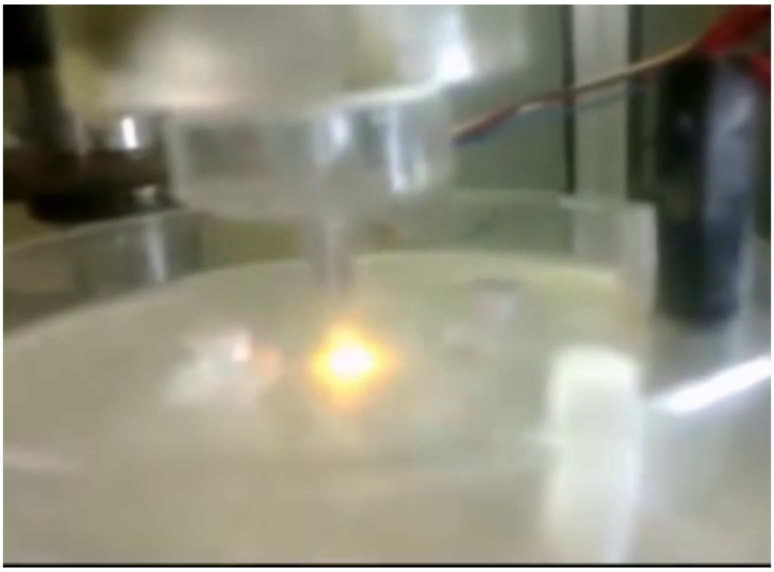

So this is occurring at the tooltip and the surrounding electrolyte, this energy of the spark is utilized for carving the micro-channels in different shapes.

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So here 4 samples are placed, 2 are class work pieces and 2 are silly gone work pieces these are treated at 50 volt DC supply between cathode and anode, cathode is 200 micro-meter copper wire, anode is graphite rod and 2 small channels are there, these needs further magnification to see properly that's why we have carried out scanning electron microscopy to study this channels. These are 2 silicon pieces and on this work piece there is a circle which is formed and on this work piece there are 2 complex micro-channels are formed.

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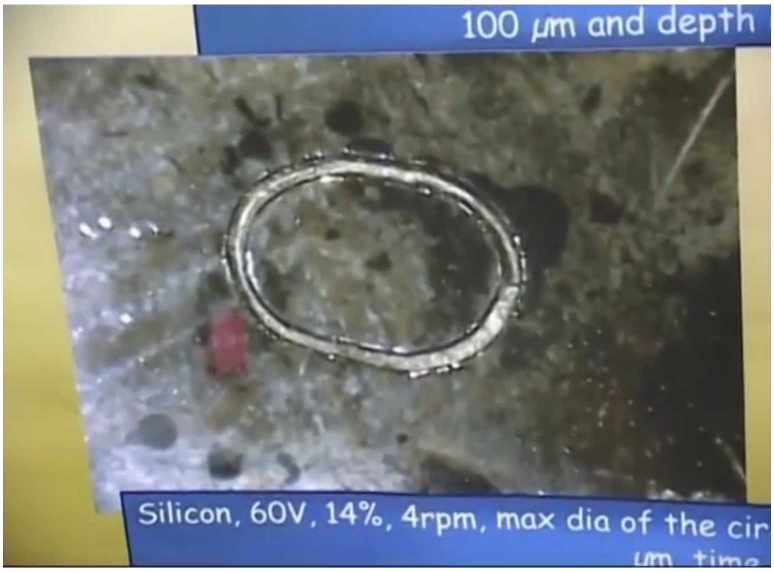

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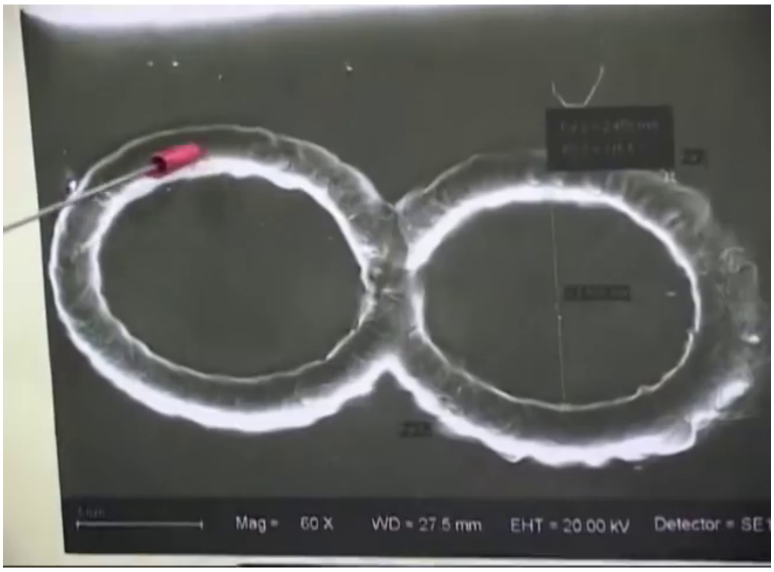

As I've shown you on the control station that we can use XY contouring mode and we can have the micro-channel in the form of circle or in the modified way we can have the 2 circles side-by-side creating a complex shape kind of infinity or 8 we can say. So these channels are formed on the glass and on silicon.

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The photograph on the right shows the surface topography of the micro-channels, these are studied using electron microscope the image can be seen at 332 magnifications and one can see how the surface is looking due to heat affected.

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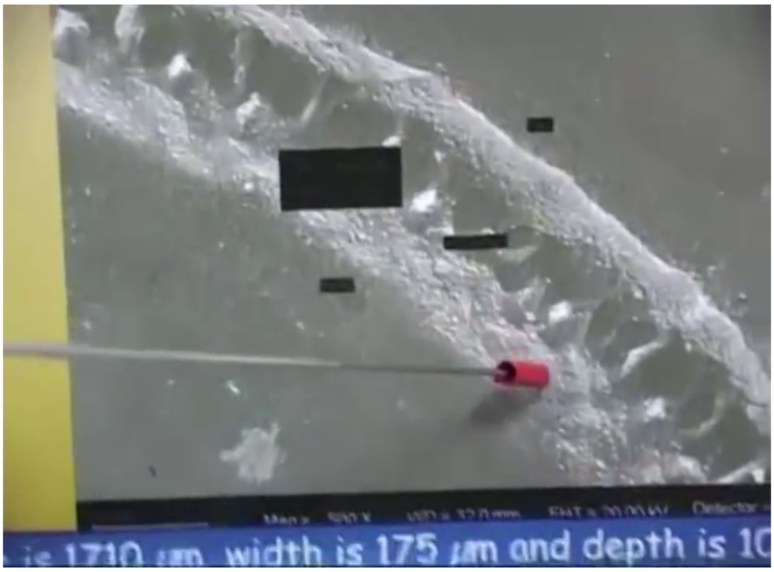

This is another channel formed on silicon, this is a part of the channel studied under scanning electron microscope the pits are seen, so this is a micro-channel and the 2 regions on the 2 sides these are heat affected zones.