Basics of Mechanical Engineering-2

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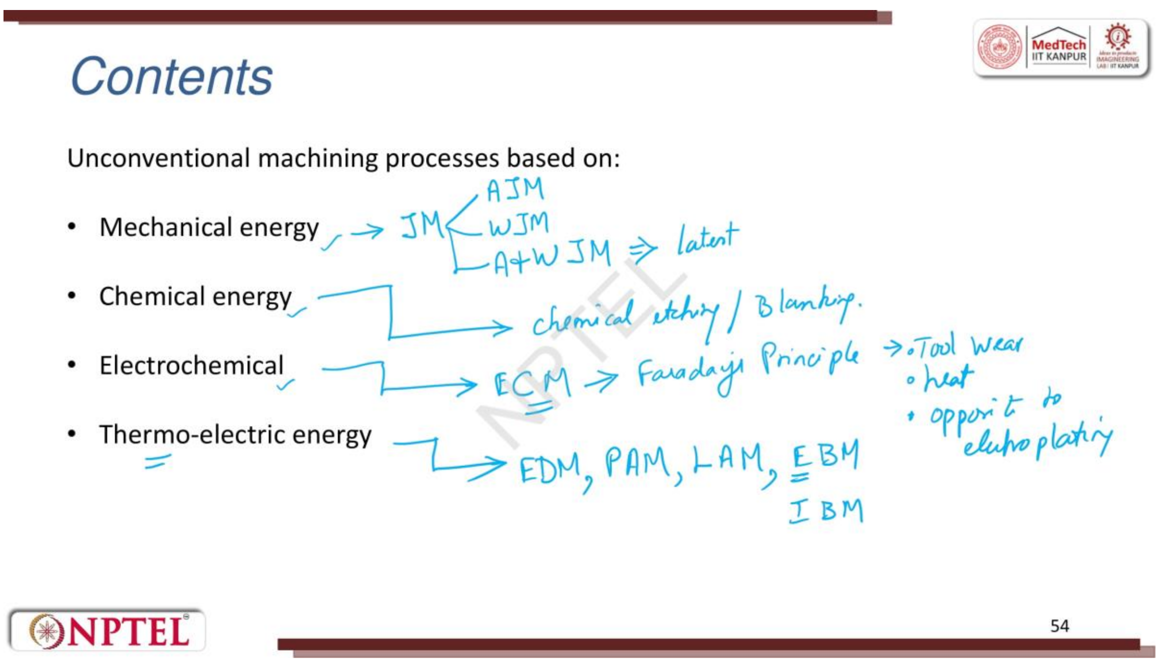
Week 11

Lecture 45

Non-Conventional Machining (Part 3 of 3)

Welcome to the second lecture on non-conventional machining processes.



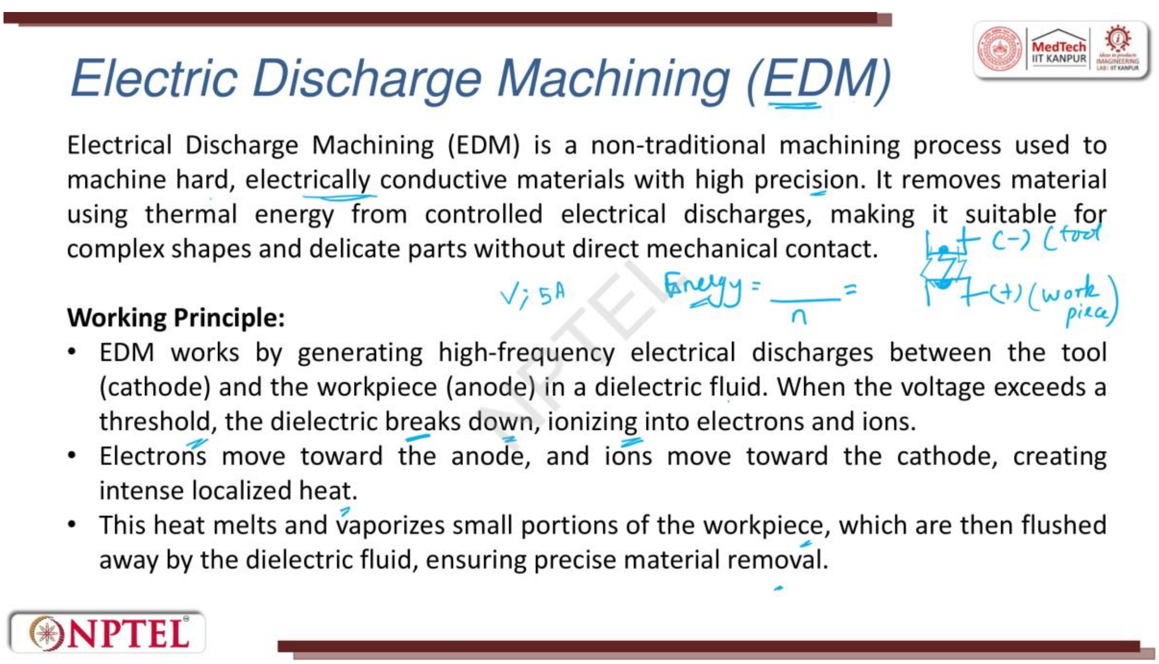
In the previous lecture, we saw mechanical energy-based processes. Then we saw chemical energy-based processes. Next, we saw electrochemical machining processes. In mechanical processes, we saw jet machining, including abrasive jet machining.

Then we saw water jet machining, and I mentioned there could be a combination of abrasive and water jet machining. In fact, this is now the latest. Many companies are using it. When we talk about chemical energy processes, it was all about chemical etching or blanking. The third one we discussed was electrochemical machining.

It is a very powerful process that works on Faraday's principle. Here, the material removal rate is directly proportional to the current we apply. Of course, selective etching and other factors come into play. But this is a very powerful tool. There is no tool wear in this process, and no heat is generated either.

So it is a cool cutting where there is no tool wear. So whatever profile you give to the tool, it can be replicated on the workpiece. It is the opposite of electroplating. The next process we will see today is thermoelectric energy-based process. In this, we will try to see EDM (plasma-assisted machining).

Then we will try to see laser-assisted machining. Then we will see electron beam machining when we talk about electrons. Then why not ion beam machining? So we will see all these processes which are thermally oriented. Some of them will be electrically activated; some of them need not be. So it is a lot, so we will try to see all these processes.



The first one is going to be electric discharge machining. Electric discharge machining is a very simple concept. I have one electrode; you have another electrode. Between these two electrodes, I apply a potential.

When the gap is too small, there is an ionization phenomenon happening. There will be a spark that happens between the two electrodes. This is a spark. So sparks are instantaneous and momentary. That means the spark will jump and then die.

Whereas, when you compare an arc in the arc welding process between the two electrodes, the gap will be too small. There will be an arc, and this arc is continuous. So please distinguish the difference between an arc and a spark. So here, what we are going to do is create a spark. The spark is nothing but a sudden discharge of energy.

So in this process, we will talk about electric discharge machining. So between the two electrodes, you apply a potential. This potential will be good enough to break the dielectric barrier in between. And create an ionization, in which there will be a spark. So, when I said an electrode, you will have 1 and 2.

1 will be negative, and 2 will be positive. The 2, the positive, will always be the workpiece. Here, this will be the tool. Now, it looks very similar to that of your electrochemical machining. But in electrochemical machining, there is no discharge.

So here, there is a discharge. When there is a discharge—a spark—there is going to be a melting of material. Which happens in the tool as well as in the workpiece. So here, the tool is going to wear out as and when the spark happens. The second thing is, between two electrodes, there can be n number of sparks happening.

So what does this signify? This says that the energy, whatever you apply, idealistically speaking, will be divided by the number of sparks. So per-spark energy will be very less. So because of this, the process is very slow as compared to that of electrochemical machining. There, it is going to be more of a dissolution.

So here it is more of a melt vaporization phenomenon. So the gap between the two electrodes dictates the spark. Suppose if the gap is very large, there is a lot of dielectric material in between. The dielectric material in between can be mist, air, kerosene, deionized water, or anything. So this is a dielectric between the two electrodes.

This is inside a tank. The electrodes are also placed inside that tank. When the energy applied between these two is high enough to dissociate the dielectric in between and create a spark. This is where the sparking happens. So electric discharge machining is a non-traditional machining process used to machine hard, electrically conductive materials.

Also, in electrochemical machining, I said very clearly, since the circuit has to be completed. The workpiece has to be conductive. Today they talk about ceramic machining also. When we talk about ceramic machining, ceramic plus there will be a metal binder. So that metal which is there makes it conductive.

So that allows for very high precision. It removes material using thermal energy from controlled electric discharge. So this controlled electric discharge is the energy that you apply. So here what we do is apply very high voltages because ionization has occurred. The current can largely go up to 5 amps.

Suppose you want a large amount of melting current. So, then we might go to 10 amps or 15 amps, but by and large, 5 amps is what we use. Some machines with very high material removal can go up to 30 amps. For very specific applications, you can go even up to 100 amps. There are requirements, but generally 0 to 30 amps is the working zone, right.

The voltages will range from 0 to 30 volts in a normal operating machine. So the EDM working principle involves generating high-frequency electric discharge between the tool cathode. And the workpiece anode in a dielectric fluid. So it is the same. In the ECM process, you have two electrodes placed inside an electrolyte.

Here, there are two electrodes placed inside a dielectric. Please understand the difference. A dielectric is used here. There, we use electrolytes. The electrolyte can be acidic, neutral, or basic.

Whereas, when we talk about a dielectric, you will not have such variation. pH variation will not be there. But you can have conductivity variation. When the voltage exceeds the threshold, the gap exceeds the threshold, and dielectric breakdown happens. What happens?

I kept on telling about dielectric breakdown. What does this dielectric breakdown mean? Between the two electrodes, you have a dielectric. Now, in this dielectric, what happens? From the tool, there will be a lot of electrons that get pushed and move towards the workpiece, which is positive. Because electrons are attracted towards the positive.

So, a lot of electrons will be moving down, a chunk of electrons will be moving down. When this chunk of electrons is moving down, During their journey, they will encounter a dielectric. This dielectric—what will happen? It will try to ionize.

These electrons will hit something, and that, in turn, will try to break. So, this is called the process of ionization, right? And when it moves down, it tries to hit the workpiece. All electrons hit the workpiece. So, a large number of electrons with energy try to hit and bombard the workpiece.

So now, when it bombards, it is trying to increase the heat there. The moment the heat is there, it exceeds and melts. So, this process is called dielectric breakdown. And ionization is electrons moving down. Similarly, the ions can also move up toward the electrons.

The ions also will move because ions are positive charge. They will get attracted towards a negative charge. But the ions number are less. They are very heavy. So for them to travel from the workpiece towards the tool is very less as compared to that of electron chunks coming and hitting.

And friends, you should also assume when the electron comes, there is a possibility of ionization initiation. And suppose if there is a resistance, the ionization dies there. Sometimes the ionization happens, but it is very weak. The spark does not happen. And the third case is, during the ionization, there can be branches of ionization.

Again, very weak energy. The last one is ionization leading to energy. So, what I am trying to say is, this ionization leading to sparking is also a random process. So, number of sparks, I do not know. Number of sparks which are getting initiated, what gets matured, that also I do not know.

This makes the process random in nature. Why am I talking more? The heat is getting hit at the workpiece. You are not able to control the workpiece roughness. So, then this process is trying to have its own difficulty.

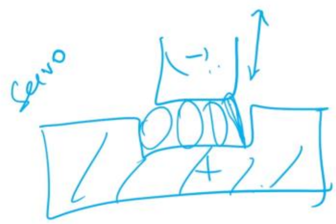
Saying this, this is the only process used for making roughness, dye material. Dyes for making injection molding dye and all, people try to use electric discharge machines. They make a tool; the tool is sunk inside the workpiece, and then they try to get it. The electrons move toward the anode, the ions move toward the cathode, creating intense localized heating. This heat melts and vaporizes a small portion of the workpiece, which is then flushed away in the dielectric fluid, ensuring precise material removal.

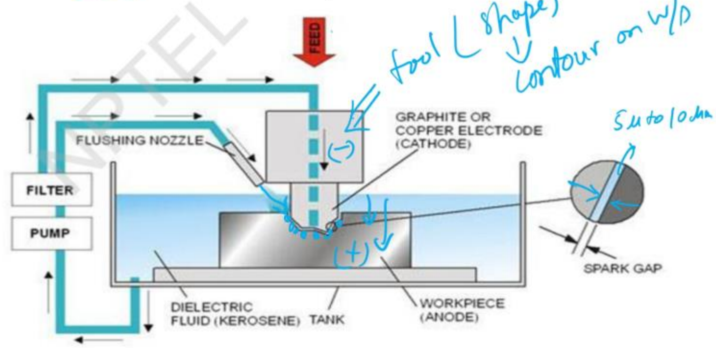
Electric Discharge Machining (EDM)

Components:

1. **DC Pulse Generator**

- This component converts the AC power supply to a pulsating DC supply high enough to generate a spark between the eroding tool and the work part.





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Electric Discharge Machining (EDM)

2. **Electrode Tool**

- The tool, connected to the cathode and mounted on a tool post, transfers its profile to the workpiece with a small arc gap. Common electrode materials are copper, tungsten alloy, graphite, steel, and cast iron.

3. **Servo Motor Mechanism**

- This mechanism controls the feed and movement of the tool in the EDM machine.
- The arc gap, previously mentioned above, is critically controlled by a programmed servo motor mechanism.

4. Spark generator

- This component supplies the right amount of voltage needed for spark generation and discharge maintenance.
- The generation of one hundred thousand sparks per second makes it possible to create a significant subtraction of material from the work part.

So, this is the process. You can see here; this is a tool. The tool is given a shape. The shape of what is the contour required on the workpiece. So, the similar one is given to the tool.

Now that is sunk inside the workpiece. The workpiece will be die steel, which is a hard material to machine through subtractive processes. Any other process, like laser, takes more time. So we would always prefer to use the EDM process. So here you see there are

There is dielectric, right? This dielectric is flushed toward the tool and the workpiece interface. Then it is also flushed through the tool. Why are they doing this too? As you go down and down and down,

there will be a lot of debris, which is material removed but gets stuck in the way. So, to remove this, we try to flush the dielectric. If you go back to ultrasonic, a similar situation can happen when you go deeper and deeper. But there, what you did was the tool went up and down. So when it moved up and down, it tried to create an agitative motion.

And the free debris, whatever is there, can easily move out. That situation is not here. So if you move up and down, up and down, up and down in EDM process. The process becomes very inefficient. So that is why what they do is they try to maintain the gap very small and dielectric is filled inside.

The dielectric is flushed. When it is flushed, it is made sure that all the small melts, vaporized material, which is the debris, can be easily removed. So generally what we do is since this is negative and positive, we always try to have a DC pulse generator. It is best to have a DC power generator or you have a AC power, convert it into a DC power. And then connect it to the machine such that you have a negative and positive.

Can I do it ulta? That means to say tool can it be positive and workpiece can be negative? Yes, you can do it. The only thing is you will never have a focused discharge. You will always have a spread discharge.

So you will never have a deep cut. You will always have a shallow cut. But the process efficiency goes low if you reverse the polarity. This component converts the AC power supply to a pulsating DC power supply. So why are we calling it pulsating?

Because in DC, what happens? You can give this: the voltage which is time. You can give continuous. This can also be given by a power supply. You can give a power supply like this.

So this is voltage, this is time, this is pulsating. If you see pulsating, the peaks can be higher. So the energy can be higher. You can also play with the shape. So, you can have a trapezoidal pulse.

Depending upon your requirement, you try to change the pulse which is getting generated that is left to you. This is called as pulse shaping. This is called as continuous current or continuous voltage supply and pulsed voltage supply. Pulsating DC high enough to generate spark between the eroding tool and the workpiece. So this is the gap which we talk about.

What will be the magnitude of the gap? This can be between 5 microns to 10 microns. This itself is very large. People talk about 1 micron to 5 microns. So the electrode material, as you know, the electrode material has to be conductive.

Second thing is it should be easily machinable. So that any complex feature which you want to replicate on the workpiece, you should be able to do it. And we also try to have a material which can withstand very high temperatures without getting worn out. The servo motor mechanism, it is very interesting to know about the servo motor mechanism. See what happens when we start moving this down, a constant feed rate is given to the tool.

When the constant feed rate is given to the tool, there might be a situation where the tool is there and the workpiece is there. There might be a situation where the debris is very big, and this debris can come in contact with the tool and the workpiece. If it comes like this, then there is something called short-circuiting happening. When the short-circuit happens, the tool has to withdraw itself because there is short-circuiting. If the short-circuiting continues, it is going to weld.

So, the tool will immediately revert back a little bit. And then it will revert back for some distance. And then it will try to reassess and see whether the short-circuiting is still happening or not. If there is no short-circuiting, then the tool will start moving down. Now, if you see, who does this movement?

This movement is done by the servo. The servo motor mechanism controls the tool, the feed to the tool, and the workpiece. The mechanism controls the feed and the movement of the tool in the EDM machine. The arc gap previously mentioned is critically controlled by a programmed servo motor. So, what we do is we try to fix a voltage. Whenever the tool and the electrode go below the voltage, it is immediately pulled up.

So, the voltage we use is a voltage to control the gap between these two. Spark generator—this component supplies the right amount of voltage needed to create a spark during the discharge machining. There can be 100,000 sparks per second, making it possible to create a significant subtraction of the material. So, the material removal per spark will be very small. But you will have hundreds of these sparks which are created between the electrodes. So, this will remove more material. So, this is spark generation.

Electric Discharge Machining (EDM)

5. Di-electric fluid

- The electrode tool and workpiece are submerged in dielectric fluid, which circulates at constant pressure to remove eroded metal particles.
- Excess pressure slows cutting, while low pressure may cause short circuits.
- Common dielectric fluids include deionized water, glycol, and silicone oil.

6. Workpiece

- This completes the EDM machine ecosystem because the work part is connected to the anode.
- To make the process possible, the work part should be a good electric conductor.

Dielectric fluid—I already talked to you about it. Dielectric fluid is very important because you have to focus the spark. The second thing is it must have a conductivity which is not too high.

So, which is not too low because if it is too low, the sparks will not happen. So, high means it will take a lot of time. So, you have to take a mid value. So, dielectric fluid generally what we use is kerosene, deionized water, or air mist. Then we also use air. This excess pressure slowly cuts, while low pressure may cause short-circuiting, right?

So, the viscosity is also very important because it has to flow through it. Then we talk about the workpiece; it has to be a conducting workpiece.

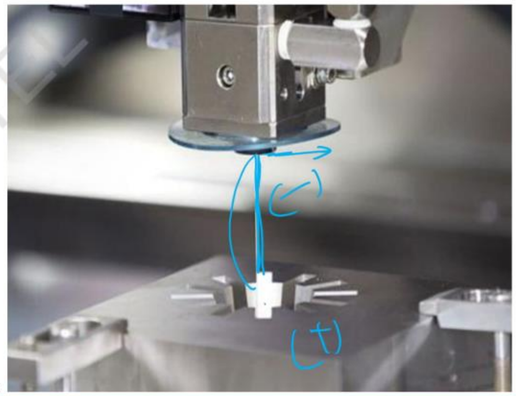
Electric Discharge Machining (EDM)

The EDM process is classified into different types depending on the shape and approach of the tool used. The three common types of electrical discharge in the industry include hole drilling EDM, wire EDM and sinker EDM

1. Wire EDM:

EDM wire cutting uses a thin copper or brass wire, guided by diamond guides, to cut precise 2D shapes on 3D workpieces using CNC control.

It is commonly used for machining metal extrusion dies, punches, and plates with high accuracy.



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So, till now, we have been talking about a tool—a tool in which you can try to give a shape to it. That shape, when you sink it into the workpiece, you are going to get. For example, you can think of this as a gear which is being machined.

So, I can try to make the complete negative of this gear and attach it to the tool. Possible, and then I do sinking. So, I make the tool, I sink. This is called die sinking. The other way around is I try to convert the tool into a wire.

Why? Because there is a lot of tool wear and the depth is too large. And I do not want to have control in Z. I want to have a through cut. Then the best suggestion will be to choose a wire as a tool.

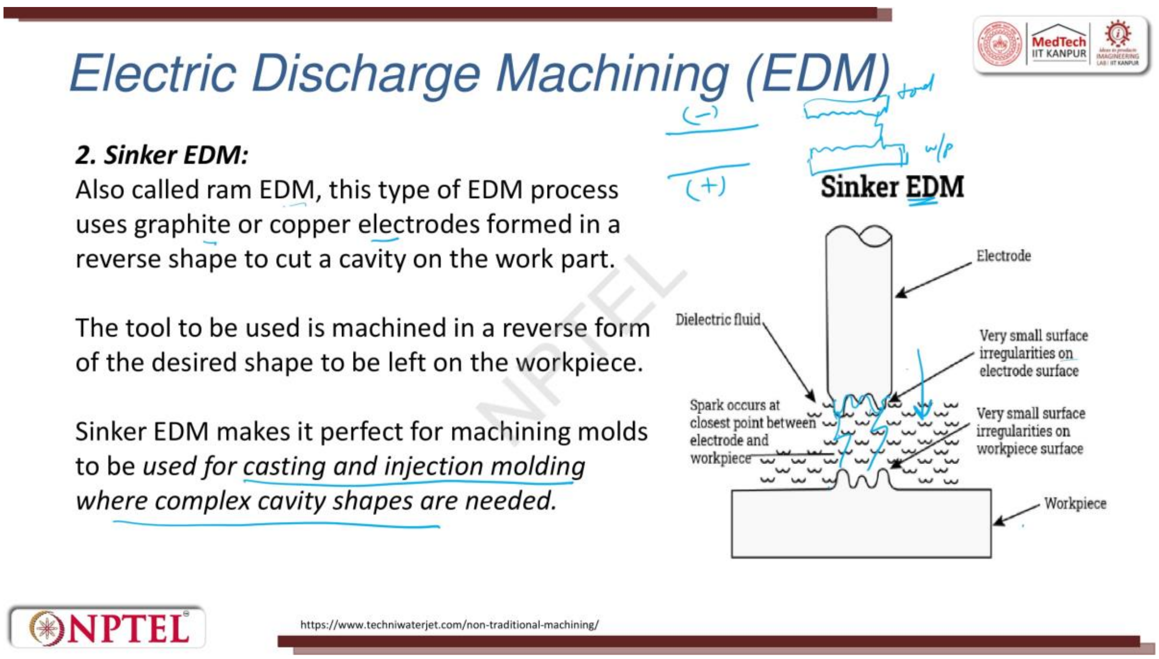
The wire becomes negative. The workpiece becomes positive. Now the wire will move around, creating a profile. Assume that you have a wire. Then, your hot wire and thermocol are ready.

Now, a hot wire can move inside the thermocol to cut a profile. For example, when you see 'Happy Birthday,' there will be a profile that is cut. How do they cut it? They just place the thermocol, use a hot wire or a knife, and then move around to create the character, whatever it is. In the same way, you can also perform wire EDM.

So, in wire EDM, the tool becomes a wire. Wire EDM cutting uses a thin copper wire. That can be a copper wire or a brass wire. Or there can be an alloyed wire or a stranded wire, whatever it is. So, a thin copper wire or brass wire is guided by a guide, as they say.

Why do they want to use a guide? Because this will vibrate. Why is it vibrating? Because every spark can create a little bit of shock, so there can be vibration. So if the vibration increases, then it will sag.

So, they want to avoid and maintain attention. So, they always use a guide. So, that is why they say diamond guides precisely cut 2D shapes or 3D workpieces on a CNC-controlled machine. So, commonly used machining materials or extrusion dies, punches, plates, and high accuracies can be achieved.

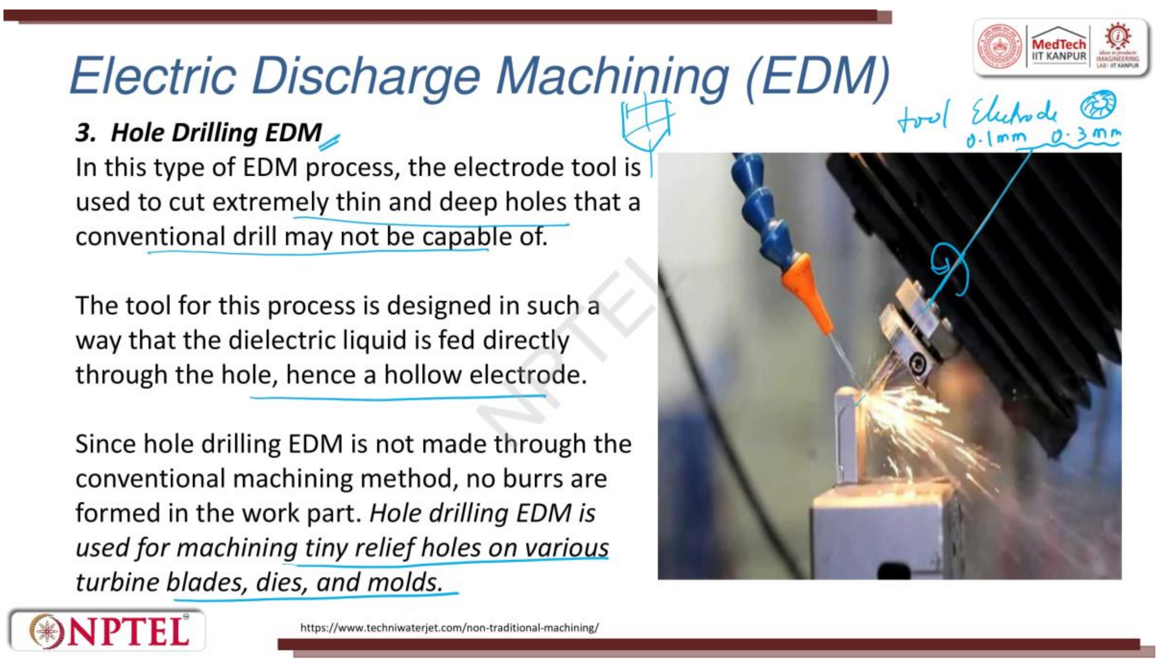


So, this is a sinker EDM. So, what we first saw was wire EDM. This is a sinker EDM. So, in sinker EDM, the profile you have to superimpose on the workpiece is given to the tool. And the tool is sunk inside the workpiece. So, that is why it is called a sunk workpiece.

Sinker EDM, dielectric fluid, the spark occurs at the closest point. And interestingly, I forgot to explain one more concept. If you have a surface, you will never have a flat one. So, this is the tool, and this is the workpiece. You will always have small asperities on the surface, and it is also interesting to know.

The ionization will be maximum with a minimum gap between the two surfaces. That means between the tool and the workpiece, wherever there is a minimum gap. There, the ionization is fast, and the spark also happens fast. So, that is why they say the spark occurs at the closest point between the electrode and the workpiece. Between the electrode and the workpiece, you get the spark. Very small surface irregularities on the electrode—these are small electrodes.

And these are very small irregularities on the surface, and this is the workpiece. So, between these two, wherever there is a minimum distance, the spark happens here. So, here, it is also called RAM EDM. In this type of EDM process, we use graphite or copper electrodes to create a cavity in the workpiece. So, where is it used? It is extensively used for casting and injection molding where complex cavity surfaces are to be made.

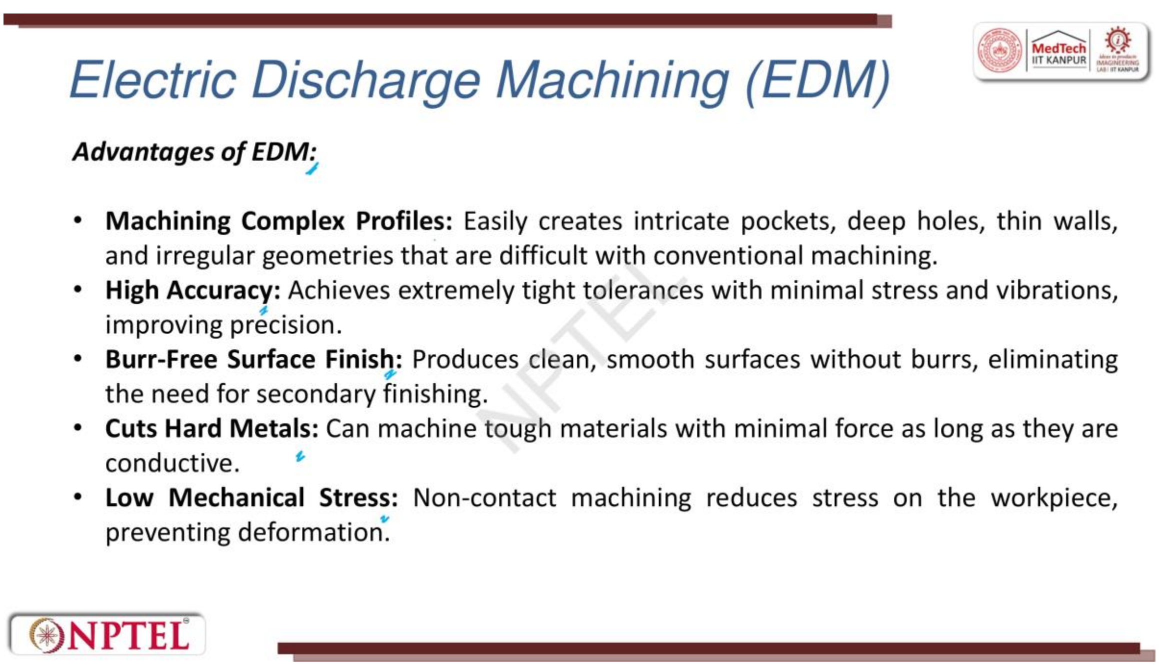


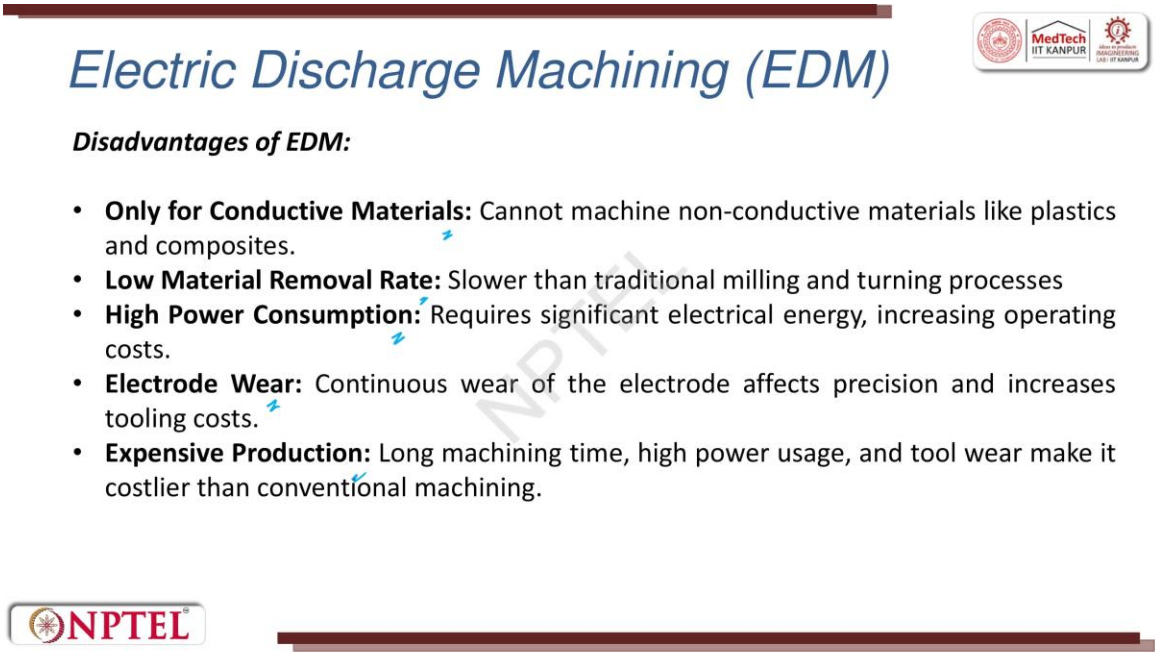
You can also have hole drilling EDM, like normal drilling where we had a flute. You remember there was a drill that we studied in the subtractive process. So, you had a drill. So, like that here also, which is used to generate a hole.

So, here the drill can be made through a drill bit. This is called a drill bit or an electrode, a tool electrode. This tool electrode will be something like a hollow pipe. Or it can also be solid. So, through this hollow, you try to pump in dielectric, and along the surface, you also try to pump the dielectric.

So, through this, I am able to drill holes in the workpiece. And if I want, I can also rotate the tool such that it can create a proper hole. So, if you do not rotate, the wear is in one angle. So, that will be super empowered and will be replicated in the workpiece. So, I try to rotate and try to sink.

So, in this type of EDM process, the tool electrode is used to cut extremely thin, deep holes that may not be possible with conventional drills. So, what we are talking about is a drill diameter of 0.1 millimeter, 100 microns to 300 microns. If I wanted to drill a hole, this is possible in the hole drilling process. It is almost the same; the tool is rotated, and the spool is sunk inside. The hole for this process is designed in such a way that the dielectric liquid is fed directly through the hole. Hence, a hollow electrode is used. The whole EDM machine is used for machining thin relief holes on various turbine blades, dies, and molds.





So, the advantage of the EDM process: Machining complex profiles can be done. You can control the energy, so it can be very high precision.

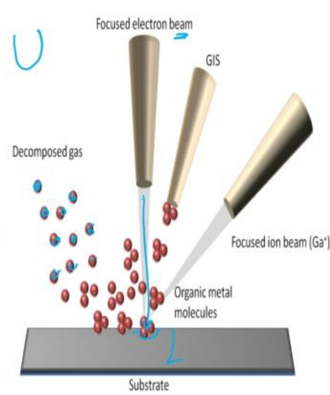
It is generally free from burrs because burrs are very common when you do a subtractive process. There will be strain hardening happening. The chip will get broken, and half of it gets retained. So, burr-free surface machining is possible. It cuts hard metals, and low mechanical stresses are always present.

There, when we try to do this EDM process. The disadvantage is it can work only on conducting workpieces. The material removal rate is extremely slow compared to that of the ECM process. Very high power consumption; ECM also has very high power consumption. The biggest disadvantage is it has electrode wear.

So, the tool profile has to be redone very frequently. And it is an expensive production process because its machining time is very long. So it is expensive, but today they have They have played a lot with the power supply and are able to achieve very high machining speeds.

Electron Beam Machining (EBM)

- Electron Beam Machining (EBM) is a **thermal process**. Here a steam of high speed electrons impinges on the work surface so that the **kinetic energy** of electrons is transferred to work producing **intense heating.**
- Depending upon the intensity of heating the workpiece can **melt and vaporize**.
- The process of heating by electron beam is used for **annealing, welding or metal removal**.
- It is a process of machining materials with the use of a high velocity beam of electrons.



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The next process is going to be electron beam machining. Here, it is dominated by electrons. It is the same there. But here, we do not perform an ionization process. Here, the electrons are allowed to strike the workpiece and remove material. Electron beam machining is a thermal process in which a stream of high-speed electrons impinges on the work surface.

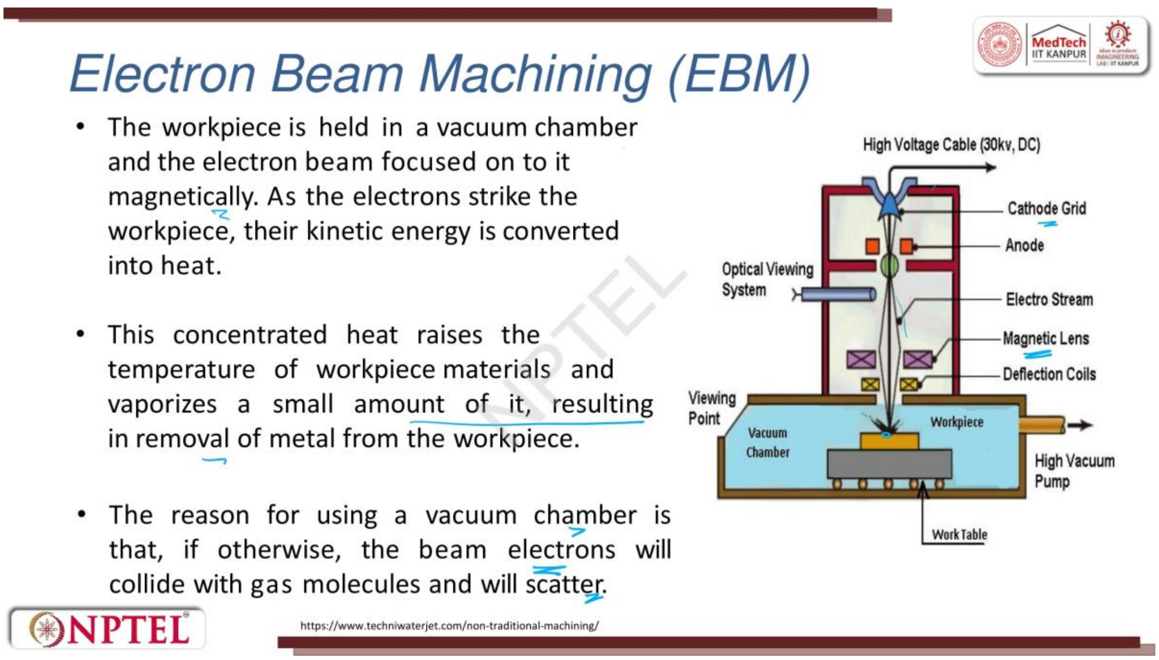
So that the kinetic energy of the electron is high which is transferred to producing an intense heating. So these are electrons. These electrons, a bunch of electrons, they come from a thermionic emission process. Source or it can be a tungsten electrode where in which you can have multiple electromagnetic filters. It extracts only electrons and allow the electrons to pass through.

And while it is coming through, you can focus it to a smaller spot and you can also increase the speed. So, when I increase the speed and focus to a smaller point. The kinetic energy of the electrons which is getting transferred produces a intense heating. Depending upon the intensity of heating, the workpiece melts and vaporizes. So the same phenomena melt vaporization also happens in EDM.

Because the electron hits, it is going to create heat, it is going to melt. And why is it melt vaporization is important? Because melting, this is a solid place and suppose if I melt. This is the melting happening but you still have a liquid vaporization. This will try to create a cavity where the molten material, this molten material is vaporized.

This is vaporized. So, that is why it is called melt vaporization. The process of heating by electron beam is used for annealing, welding, and material removal. So, if you see here, this is a focused electron beam, and this is a gas. So, this is almost like deposition can also happen.

But this is a focused electron beam. This focused electron beam hits the workpiece. So, when it hits, it tries to remove, but the amount of material removed is very, very small. Very small—you do it like 0.1 or maybe 20 microns per minute. So, that is the rate they do—very small, but it is very focused, and you can also develop very sharp and deep holes.

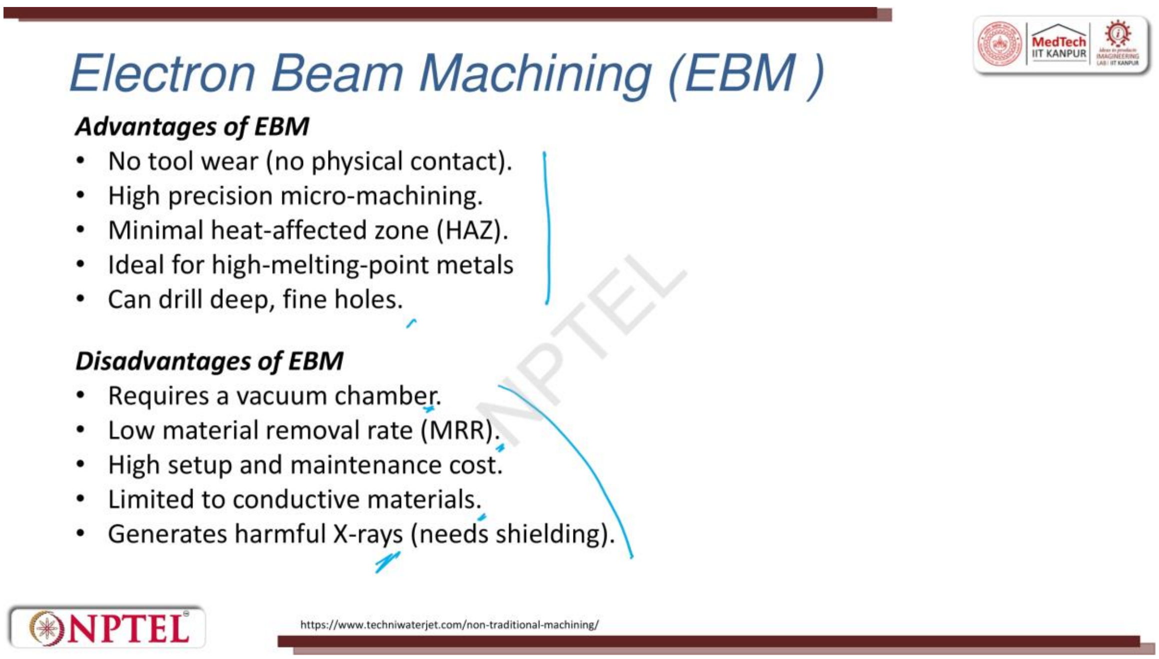


So, the workpiece is held in a vacuum because the electrons are there. The workpiece has to be kept in a vacuum. Otherwise, the workpiece will try to hit the gas molecules. And you will try to create a spark, or it will make it inefficient. The workpiece is held in a vacuum chamber, and the electron beam is focused onto it magnetically. The electron beam is focused on it magnetically.

So, you can see magnetic lenses. So, this is what I said high voltage cable is done. So, then you have a cathode grid. So, this cathode grid protects produces there is an anode. So, anode removes all the electrons and then it tries to focus.

Now onwards you can see that there is the electron stream which expands. Then you put a lens to focus, then you put a deflecting coil to focus and it focuses on a small point. So, as the electron strikes the workpiece, their kinetic energy is converted into heat. This concentrated heat raises the temperature of the workpiece. And vaporizes a small amount of it resulting in removal of metals from the workpiece.

The reason for using vacuum chamber is that if the beam electron will collide with the gas molecules. And it might get scattered, which is quite common in EDM process.



So, these are the advantages there is no tool. So, there is no tool where very high machining minimum heat affected zone the ideal for high melting point metal. So, suppose you want to make tantalum tungsten crucible then electron beam is an example which you can think.

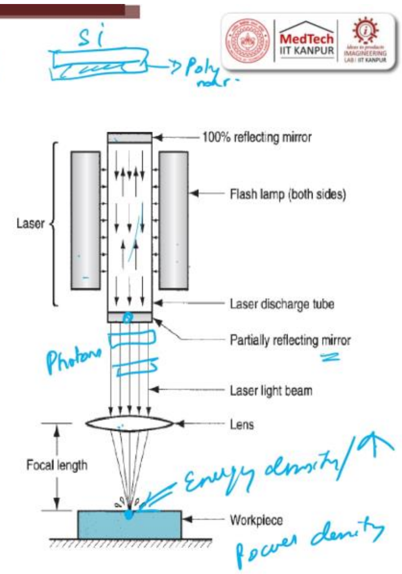
It can be used for drilling deep holes and fine holes. What are the disadvantages? There is a vacuum chamber. So, it always puts a restriction on the size of the workpiece. Its material removal rate is extremely low. It is limited to conducting materials. Sometimes, when the electron hits, it can even generate X-rays. So, it needs proper shielding.

Laser Beam Machining (LBM)

A laser is an optical transducer which converts the electrical energy into coherent light. Laser stands for *"light amplification by stimulated emission of radiation".*

The laser being coherent or consistent in nature a specific property to generate high power density. The laser is man-made ruby crystal, containing chromium or Aluminium oxide. LBM uses the light energy of a laser beam to remove material by vaporization and ablation.

In this process, the coherent or consistent light beam is focused optically for a particular period of time.



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From there, we had a restriction on the machine size because of the vacuum. Now, here is a process in which we do not use a vacuum but still try to generate that heat. So, how do we do it? We do it by laser treatment. Laser is a wonderful tool. It can give you multiple wavelengths. For example, you can have green light, blue light, red light, or whatever it is.

And each of the lights means to say there is a wavelength. This wavelength tries to selectively interact with the workpiece. For example, if you have a polymer coating and a ceramic coating. And a polymer coating, you want to make it transparent through the ceramic and then heat the polymer. So, I am trying to tell a sandwich.

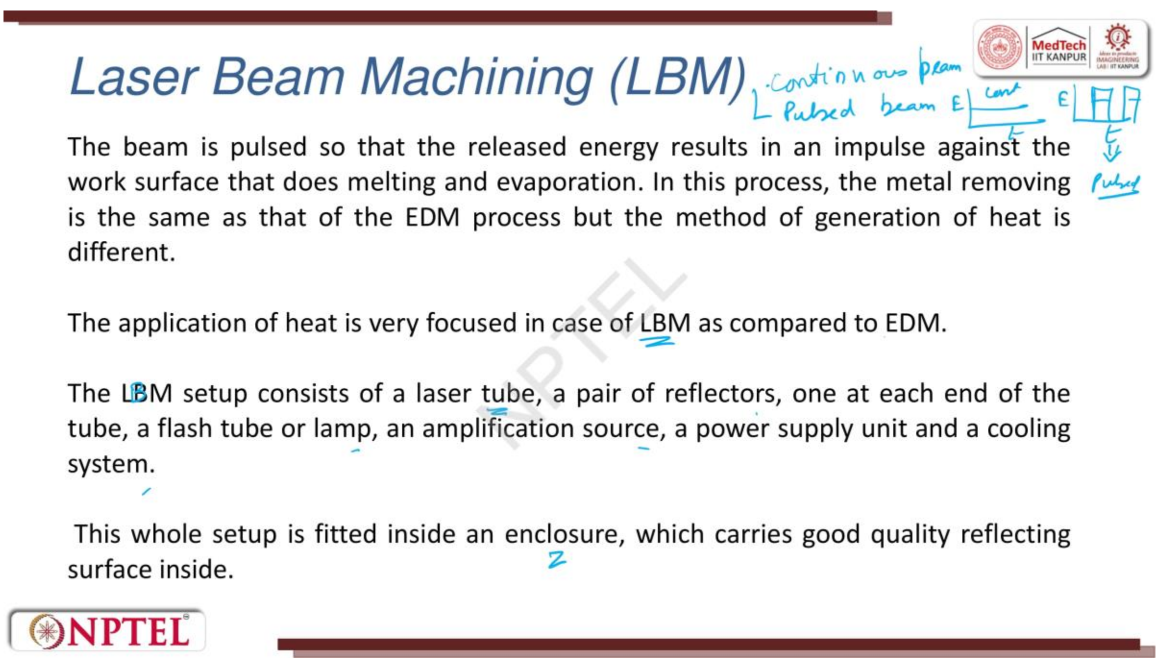
This is a silicon ceramic, and here is a polymer coating, right? Idealistic case: polymer coating. Now, the laser will not do anything. For silicon, it will be transparent. When it meets a polymer, it will start machining.

It is selectively machinable. The laser is an optical transducer that converts electrical energy into coherent light. The laser stands for light amplification; the expansion for laser we are saying. Light amplification by stimulated emission of radiation. How is this laser happening? We talk about a concept called inverse population and other things.

We will not get into that right now. You have a photon, a packet of energy which is called a photon. These photons are focused by a lens onto a point here. When you focus it to a point, there is what is called energy density or power density. That means to say, on the spot diameter.

What is the energy you apply? So the energy density will be very high, or the power density will be very high. When the energy is very high, again, melting phenomena will happen. The laser, being coherent and consistent in nature, has a specific property to generate very high power density. So, till now, we have made ruby crystal, chromium, aluminum alloy, and so many variations.

We have gas lasers, solid lasers, and then you have electronic lasers, right, which are made out of silicon wafers—low-power lasers. So, you also have dye lasers. So many different lasers are there. Depending upon the medium—the lasing medium— You can try to get the power output; you can try to get the color wavelength. In this process, the coherent or consistent light beam is focused optically on a particular point at a particular time. So, you try to get material removed.



The beam is pulsed here; also, you can have a continuous beam—the laser beam. You can have a continuous laser beam. What do you mean is continuously giving a constant power supply or another one.

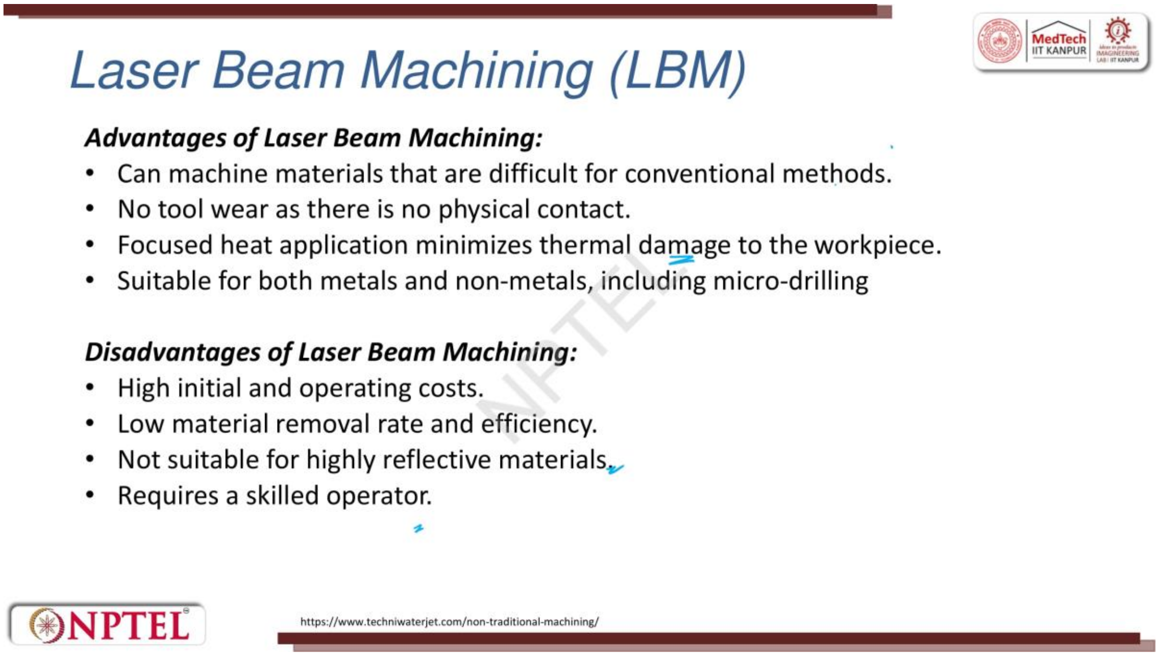
You can also have pulsating; today, we use pulsed laser beams, right? So, in pulsed laser beams, as I told you, this is the continuous laser, and in pulses, what will happen is you will get very high-energy pulses. So, this is E versus T; this is E versus T—this is continuous, this is pulsed. You have very high energies in a very short duration of time. So, this will try to melt and vaporize material very fast.

The beam is pulsed so that it releases energy, resulting in an impulse against a work surface that melts and evaporates. In this process, material is removed the same as in the EDM process or EBM process. The application of heat is focused in the case of LBM as compared to that of the EDM process. The LBM setup consists of a laser tube, a pair. So, I am talking about a very primitive one; it consists of a laser tube.

Inside the laser tube, you will have a lasing medium. Then you have the tube closed on the top side: 100 percent reflecting and 99 percent reflecting. And this tube's lasing medium is activated by a flash light, a ruby light, on both sides. So, when this flashlight flashes a light, the medium inside gets energized. Then it tries to move back and forth because it has a 100 percent reflecting and a partially reflecting side.

So, it goes back and forth repeatedly. The moment it reaches a threshold value, the laser exits from the partially reflecting mirror. So, that is how the laser is produced. Today, you have semiconductor lasers. So, the phenomena are different.

So, what we talk about is the same: the laser tube. It has a pair of reflectors, one on each side of the tube, a flash tube or a lamp, an amplification source, a power supply unit, and a cooling system. This whole system is fitted inside an enclosure, and you can achieve very good quality machining processes.



So here, the advantage is the interesting part of the laser. I can keep the laser at the corner of the room and the workpiece at the other extreme corner. And this corner-to-corner distance can be 10 meters, 50 meters, 100 meters, or even a few thousand kilometers. The laser can travel. That is the advantage of a laser. So you can place the workpiece anywhere, try to hit it, focus it, and hit it—it is possible. So the energy travels.

It does not depend on the medium. And it can machine materials of any kind—conducting, non-conducting, anything. So, that is very difficult to machine conventionally. There is no tool wear because the laser is used. The focused heat application minimizes thermal damage.

It is suitable for metal, non-metal—anything, metal or non-metal. It can do laser milling, laser drilling, or laser etching. Etching means a very small depth of cut. Everything is possible with a laser. A laser is a very versatile tool.

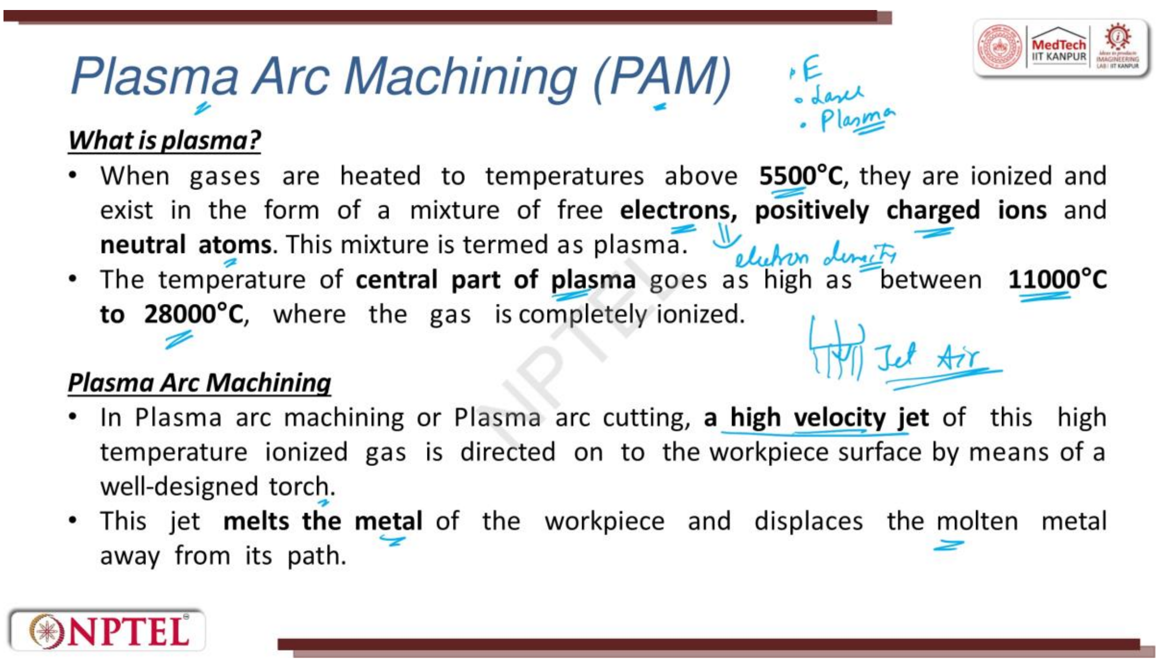
But what are the disadvantages? It is costly. The material removal rate is low compared to that of a subtractive process. It is not suitable for highly reflective surfaces. For example, here we do not talk about the thermal conductivity of the material.

We talk about the reflectivity property of the material. If a material is completely polished, the laser hits and gets reflected. It does not machine. So that is the problem we have to address, and the laser really needs a skilled operator. Because depending upon the workpiece, you have to optimize the parameters, focus, defocus, and do many things.

And it is also interesting that you can also have a fluid, a coolant, to flush. Let me give you a very practical example. If you have a diamond or any precious stone and you want to engrave that stone with your name. Ram, Shyam, Rishi, right. You want to, John, you want to do it.

So now you can engrave it through a laser. But you should understand, if the heat is getting focused and it is there for a longer time, it can shatter the stone. Now what you have to do, you have to extract the heat instantaneously. So what they do is, they try to keep a stone, precious stone. They try to use a laser to engrave and parallelly they also use liquid nitrogen to extract the heat very fast.

If they do it very slowly, the stone gets shattered. So you need a skilled operator to understand and then do it. That is what they have written it here.



The next process is plasma arc machining process, PAM. So here plasma. So first we saw electron. We saw laser. Now we are seeing plasma. What is plasma? Plasma is the fourth state of material.

When a gas are heated to a temperature above 5500 degree Celsius. They are ionized and exit in the form of a mixture of free electrons, positively charged ions and neutral atoms. This mixture is called as plasma, 5500 degree Celsius. So, free electrons, high energy is there, positively charged ions. That fellow is also heavy and then there and you have neutral electrons.

When all these fellows are mixed together and when they are focused on a point, they try to remove material. The temperature of the center part of the plasma can go as high as 11000 degree Celsius to 28000 degree Celsius. The gas is completely ionized. The plasma arc machining. So, it is a plasma and interestingly, you do not have to have hot plasma around.

In the sun, you have a hot plasma. If you go down, if you go down and when you buy toys, you can see inside a glass. Inside a glass, there might be two electrodes which creates a lightning. That also is a plasma. So plasma can be cold plasma, plasma can be hot plasma.

So the plasma we are discussing here is only hot plasma. Plasma will have electrons we talk about. It talks about electron density. The amount of electrons present in one unit area. They talk about 10 to the power 23, 10 to the power 25, something like that.

Electron densities. The electron density dictates whether it is hot plasma or cold plasma. In cold plasma, you can wash your hands. You can wash your hands. All the germs will die.

You can wash your hands, right? Cold plasma is used for sterilization. So, do not think only hot. You also have a cold extremity, right. But the plasma is the same, right.

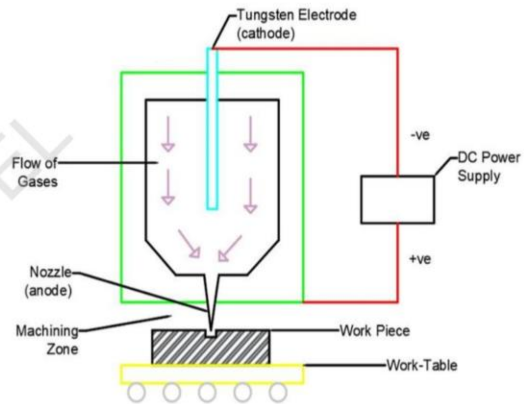
The plasma arc machine or the plasma arc cutting machine uses a high-velocity jet. So, what is that? How do you generate a jet? So, you have plasma. This plasma is created in a jet of air.

An air jet is used. So, the jet comes with very high velocity. The plasma is there. So, the jet has high velocity. That creates a high-velocity plasma cutting.

The ionized temperature is directed onto the workpiece surface by means of a torch. So, torch—what will happen? Through a torch, you apply a jet of air. The jet melts the metal and displaces the molten metal from the path.

Plasma Arc Machining (PAM)

- The heating of workpiece material is not due to any chemical reaction but on account of the continuous attack of electrons which transfer the heat energy of high temperature ionized gas to the work material.
- This process can, therefore, be safely used for machining of any metal, including those which can be subjected **to chemical reaction**.



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The heating of the workpiece material is not due to any chemical reaction. But on account of the continuous attack of electrons, which transfers the heat energy of the high-temperature ionized gas to the workpiece. So, this process can therefore be safely used for machining, which includes those that can also be subjected to some chemical reaction made possible by plasma.

Plasma Arc Machining (PAM)

Advantages of Plasma Arc Machining (PAM):

- Can cut hard and high-strength materials like stainless steel and titanium.
- Fast material removal rate compared to conventional machining.
- No direct tool contact, reducing tool wear.
- Can cut both conductive and non-conductive materials with modifications.

Disadvantages of Plasma Arc Machining (PAM):

- High initial setup and operational costs.
- Produces a heat-affected zone (HAZ), which may affect material properties.
- Not suitable for precision machining due to rough surface finish.
- Noisy and generates harmful fumes, requiring proper ventilation.

So, again, advantages and disadvantages: this high-hardness material, fast material, because of the jet, there is no contact. So, there is no tool wear, and it can be used for both conducting and non-conducting materials. So, disadvantages: high initial cost, it produces a high heat-affected zone, and it is not suitable for precision cutting.

Ion Beam Machining (IBM)

- Ion Beam Machining enables atomic-level precision machining in a vacuum environment, ensuring a contaminant-free, contactless process with no tool wear or heat damage.

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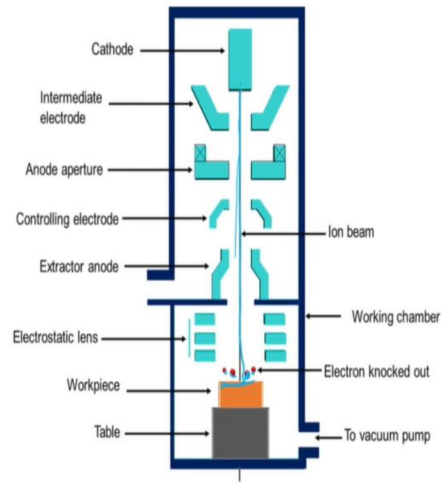
- It allows high aspect ratio machining, nano-patterning, and etching, making it ideal for MEMS, semiconductors, and optical coatings.
- IBM is highly effective for ultra-hard and brittle materials, offering exceptional accuracy in advanced manufacturing.



https://www.techniwaterjet.com/non-traditional-machining/

Ion Beam Machining (IBM)

- The **Ion-Beam Machining (IBM) setup** consists of an **ion source**, which generates and accelerates ions (commonly argon) using an electric field.
- The process takes place in a **vacuum chamber**, which maintains a low-pressure environment to prevent contamination and ensure precise ion movement.
- A **workpiece holder** securely holds the material in position and may rotate it for uniform machining.
- An **electromagnetic field system** controls the direction and focus of the ion beam to achieve accurate machining.
- Finally, a **neutralizer and collection system** captures excess ions and prevents unwanted charge buildup, ensuring process stability.

And it is noisy and generates harmful fumes while cutting. The last process we are going to see is Ion Beam Machining, plasma arc machining, ion beam machining, and electron beam machining. They are all peculiar or not very commonly used. Ion beam is also used for machining a small amount of material from a silicon wafer or from a small polymer sample. Or to make features on a silicon wafer, which can be used as a die for something.

So, ion machining involves a very small amount of material removal. Ion beam machining enables atomic-level precision machining inside a vacuum environment. Whether it is electron beam or ion beam, you need a vacuum. So, in electron beam, you had a source where you extracted electrons and pushed them down. Here, you will extract ions and push them down.

That is the only difference. And all through the way you will have almost the same thing. Magnetic lens will be there. So you play with the current. So that creates an EMF around it.

So all these things are very similar. But the only difference is if you want to make high aspect ratio machining, ion beam is much better than electron beam. It allows high aspect ratio machining, nano patenting. Nano means the feature size is 10 to the power minus 9 meter. Your hair size is 100 micron.

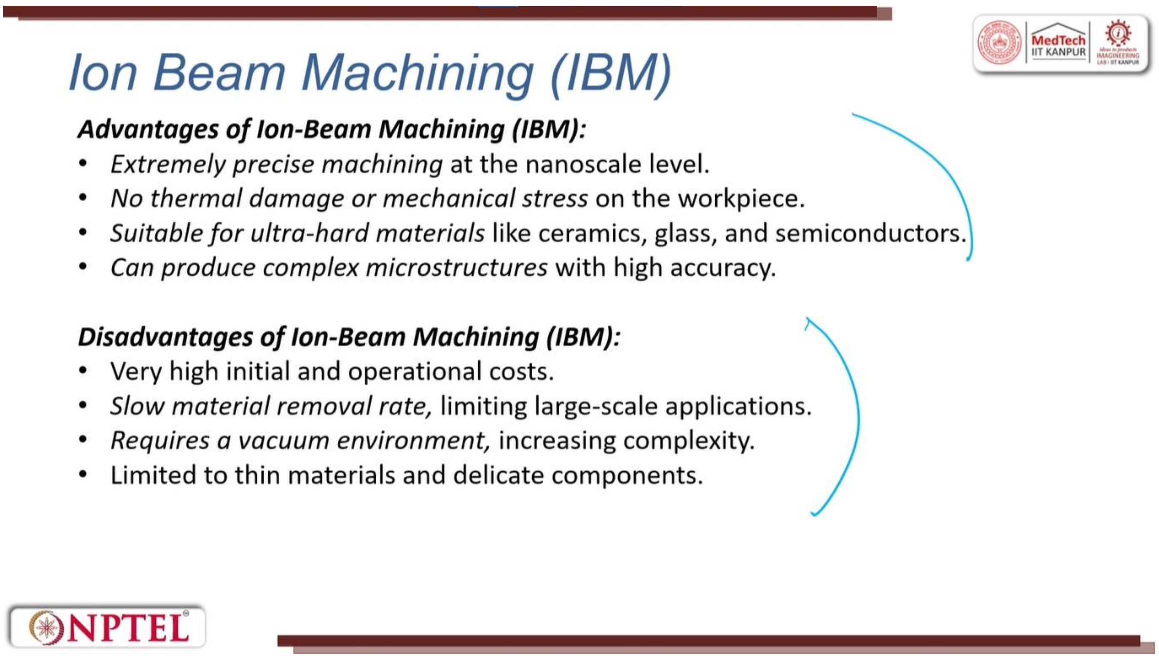
So, we are talking about one order less than that, 10 to the power minus 9 meter is a dimension. Etching, making it an ideal MEM structure, semiconductor and optical coating. So, all these things we try to use ion beam machining. Ion beam is highly reflective for ultra hard and brittle materials, offering exceptional accuracy in advanced manufacturing. So here the process is very same.

The ion beam tries to come and hit the workpiece. When it hits the workpiece, the process of material removal is called sputtering. It sputters. Sputter means like a flower pot. The material gets sputtered.

Sputter means it just explodes. When a bomb or electron hits, it explodes from there. So, you will have a lot of small, small material which is getting. So, that process is called sputtering. So, the ion beam is highly effective for ultra-hard brittle materials, offering exceptional accuracy in advanced manufacturing.

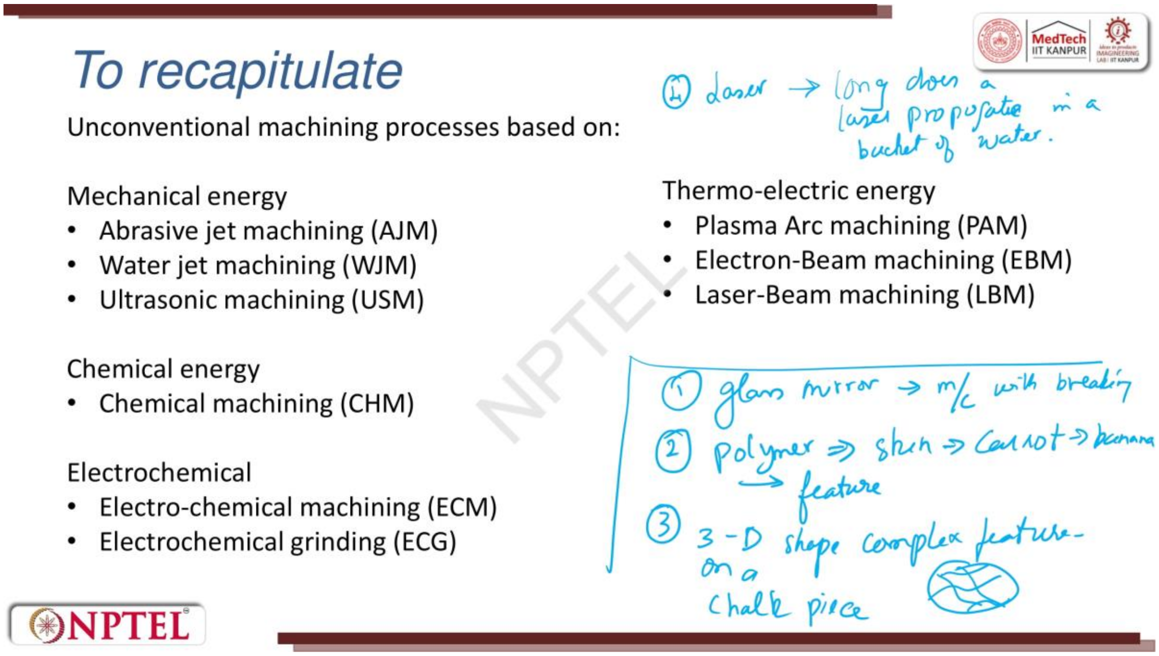
The ion beam setup consists of an ion source which generates. This is an ion source which generates ions and then accelerates them using an electric field. So, the entire process happens in a vacuum chamber. The workpiece holder securely holds the workpiece. An electromagnetic field system, these are all electromagnetic field systems like you see here.

These are all electromagnetic field systems used to control the direction and focus the flow. Finally, a neutralized collection system captures the excess ions and prevents unwanted bombardment.



It has the same advantages and disadvantages. Extremely precise machining at a nanoscale can be done. No thermal damage occurs when the ions are very small, so the damage is also minimal.

So, very hard materials, as I told you—tungsten, tantalum, foils—can be machined. It can also produce complex microstructural shapes. Very high initial cost because ion beam machining machines cost around a few crores. The metal removal is extremely slow, but we still use it for required applications. Silicon wafer dies are made through ion beam machining. So, it is used in a vacuum and is limited to only thin material machining.



To recap what we saw in both lectures, it is a very interesting topic—non-conventional machining processes. First, under mechanical energy, we saw abrasive water jet. Under mechanical energy, we saw abrasive water jet machining. Then, I introduced the concept of combining water and abrasive.

Then we saw ultrasonic machining. Then we entered into chemical machining. Then electrochemical machining, one advancement in electrochemical machining is electrochemical grinding, which we saw. And in the second lecture, we saw plasma arc machining, electron beam machining, electric discharge machining, and ion beam machining. So, it is a spectrum of processes.

We have given an exposure to a spectrum of processes. So, as an engineer, when you get into a shop floor or when you look at a product, you can understand what type of machining process is possible. So, now, I have a set of questions to ask. First question: take a glass mirror,

which is used in your house, and try to machine it without breaking it; it should not shatter. Try to engrave your name. See how it is possible. It is a challenge, but at least you can spend time and see what it is. Second, you have a polymer, or a material, something like skin, or you can take even carrot skin or some banana skin. And on it, try to make a feature. Again, try to write your name and see how you can engrave it. Observe what difficulties you encounter.

It is a soft material, banana skin, and there you try to write your name, Ram, Shyam, Sita, Geeta, you write it. And then you see how much time does it take, how do you take, and what are all possible things. And friends, when I said you try to write, you also can think of a process like stamping. But again you have to make a stamp. So keep that in mind.

Third thing is I want you to make a 3D shape. 3D shape, complex feature. Like what? Try to make an egg. This is an egg. Try to make a feature, complex feature like this on a chalk piece. And try to look at the tools what you use. How do you control the cutting and how do you do angle cutting? The last one is try to use laser. Today lasers are there, pointers are there, wonderful pointers are there.

Try to use a laser and see how long a laser propagates in a bucket of water. How long? That means when you take a 15-liter bucket, you hit the laser on the top. Will the laser travel down? Or when you make it 10 liters, will it travel down?

And when it travels down, do you see the same spot size? And when you do this, also try to disturb the water and then hit the laser. You see what happens to the spot. If you do all these exercises, which are there, these are something that is available. You will start appreciating the process, whatever it is. So we have spent a lot of effort in preparing this slide.

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So these are the references we have used. Thank you very much.