Advanced Manufacturing Processes
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Module - 3
Advanced Machining Processes
Lecture - 17
Variant Processes in ECM: ECG, ECH, ECDe and STEM

Welcome to this session on electron beam machining and iron beam machining, under the course advanced manufacturing processes. In the previous sessions, we have discussed about the electro discharge machining process, electro chemical machining process, laser beam machining processes, and some variants of these processes in details. Let us move ahead and discuss some more interesting processes, like E B M and I B M, that is electron beam machining and iron beam machining, these two processes are basically used for precision machining of materials or components, and considered to be highly precise and costly processes.

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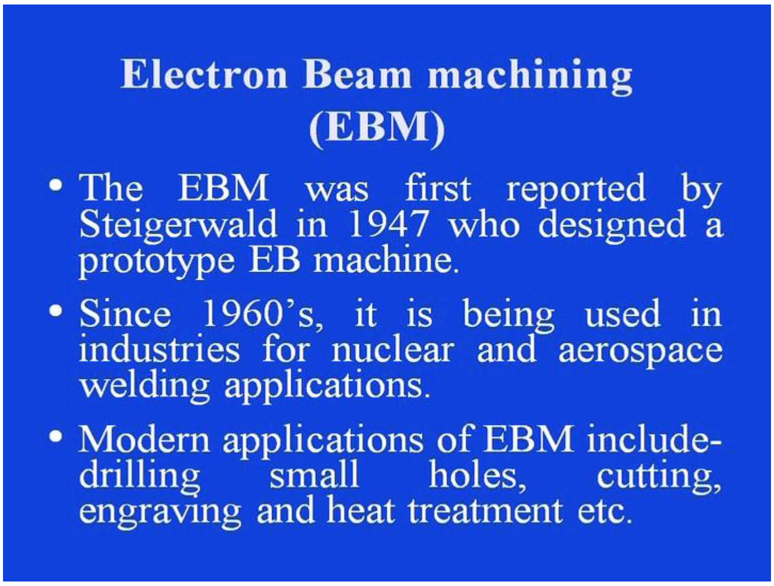

Electron beam machining, this was first reported by Steigerwald in 1947, who designed a prototype of this particular machine. Since, the year 1960, it is being used in industries for nuclear and aerospace welding applications. However, modern applications of electron beam machining include drilling small holes, as I have already indicated basically it is used for precision machining of components then precision cutting, engraving, and heat treatment, etcetera.

This process also finds applications mostly in semiconductor machining, as well as micro machining areas. The main components of this electron beam machining setup is shown in the following figure, this is basically housed in a vacuum chamber and the vacuum is maintained approximately at about 10 to the power minus 4 torque.

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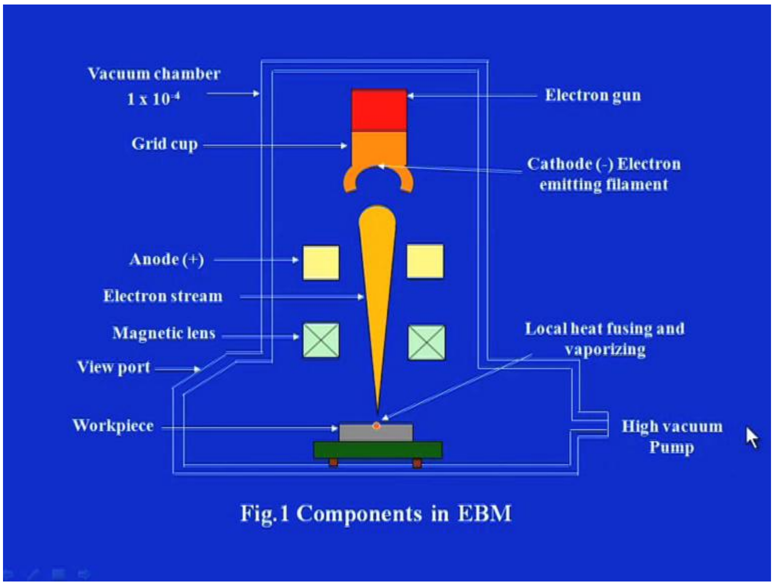

Fig.1 Components in EBM

This is a schematic of this process. So, this is the vacuum chamber we are talking about, this is in the screen we can see. And this is the cathode from which electrons will be emitted and this beam of electrons will be accelerated, towards the other end in which the work piece will be mounted. This beam of electrons will hit the work piece and the work piece will get heated, and the material gets melted and evaporated. There will be other arrangements like since, there is a cathode there will be an anode going to reach this electrons coming out of the cathode, will be attracted towards this anode.

However, there will be some other arrangement of accelerating this electrons, and instead of this electrons being getting accumulated on the anode, they will be directed towards the work piece, which we can say the focusing of the electron beams by means of some magnetic lenses as shown here, these are the pairs of magnetic lenses. So, they will be so adjusted that this electron beam will be focused at a point, where the work piece will be kept thus because of focusing of this highly accelerated electron beam. So, this intense heat will be generated, where the electrons will be striking the work piece and this piece the work piece will get melted.

The only critical thing here is the maintenance of vacuum, a high vacuum to the tune of approximately 10 to the power minus 4 torque should be maintained, and this is that is why this entire chamber is connected to a vacuum pump, and this vacuum can be monitored to maintain at a particular level. In this set up a tungsten filament cathode is heated to about 2500 to 3000 Celsius in order to emit electrons. The effect is measured by the emission current which is of 2,200 milli ampere in magnitude and its density is between 5 to 15 amperes per centimeter square.

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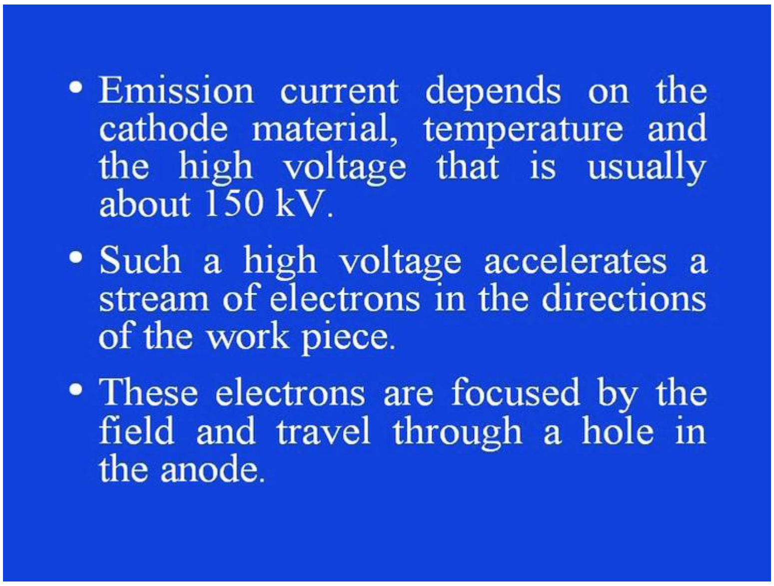

Emission current depends on electrode material, temperature, and high voltage that is usually about 150 kilo volt, such a high voltage accelerates a stream of electrons in the directions of the work piece. These electrons are focused by the field and travel through a hole in the anode. These generations of electron beam can be explained like this.

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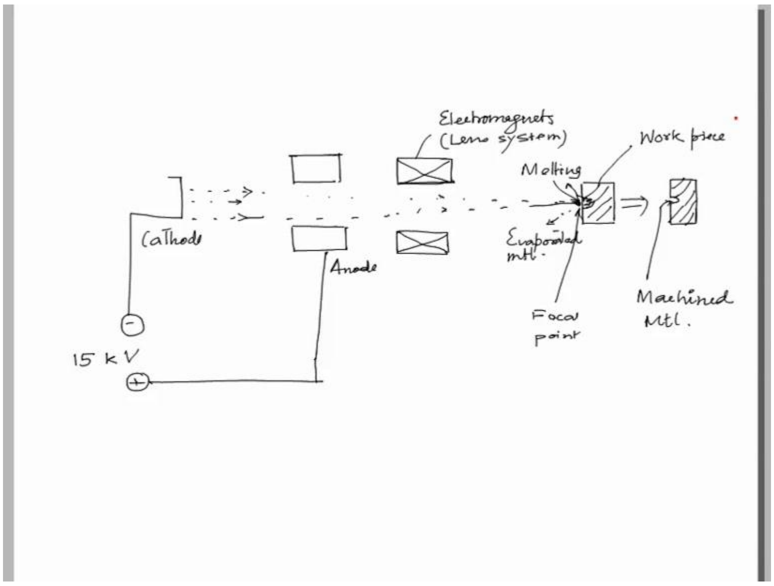

Say for example, this is a cathode which is connected to the negative end of the power supply and there is an anode. However, the peculiarity of this anode here is that, this is having a hole and this is connected to the positive end of the power supply, and this therefore, this is something around 15 kilo volt will be applied between this cathode, this is the cathode and this is the anode because of this application of this high voltage, there will be steam of electrons coming out from this cathode and will move towards, this anode.

However, there will be a system of electromagnetic lenses placed on the part of this moving electrons, in such a way that these electrons will be focused or rather this beam of electrons will be focused at a particular point. So, this is the we can say the focal point and this is achieved by this pair of electromagnets or we can say lens system, they are acting as the lens for the beam of electrons, like the optical lenses used for optical signals.

Now, this electrons if we allow them to fall on a material, which is nothing but our work material then this intense heat of this electrons generated, due to the heating of the high velocity electrons on this work piece surface, will cause the material will melt here so the melting of the material will take place locally on this portion, and then on subsequent heating of this electron beam, on to this same work piece then these material will come out as the evaporated material, evaporated material. And the ultimate result will be we will get a sort of curve or a machined portion on this work material. So, this we call as the machined material. So, this is the basic principle involved in electron beam machining.

The electron beam is pre focused by a magnetic or electronic lens system so that the beam is directed under control towards the work piece. The kinetic energy of the electrons is then rapidly transmitted into heat causing a corresponding rapid increase in temperature of the work piece, which causes material removal by evaporation with the power densities of 1.55 mega watt per millimeter square, virtually all engineering materials can be machined by this process. The mechanism of penetration of electron beam in the work material, and its material removal is yet to be understood well.

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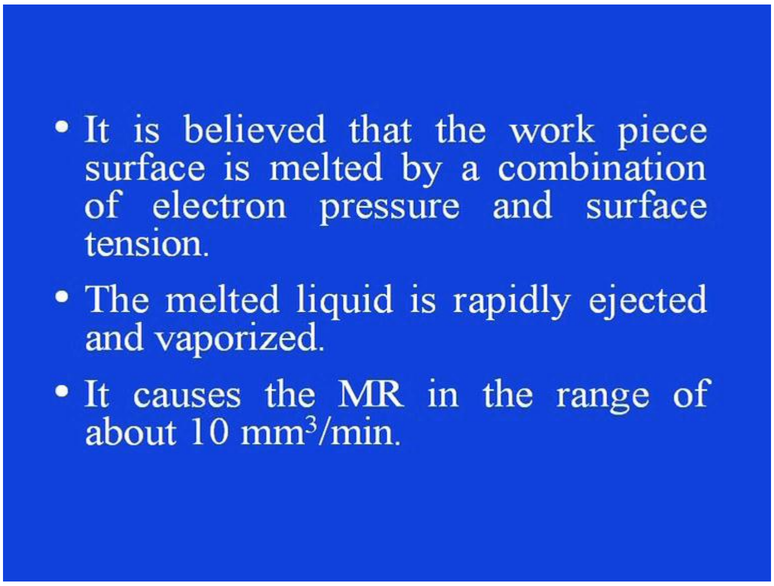

It is believed that the work piece surface is melted by a combination of electron pressure and the surface tension. The melted liquid is rapidly ejected and vaporized as we have already indicated it causes, the material removal in the range of about 10 millimeter cube per minute. The essence of mechanical contact, and the suitability of automatic control enhance, the process capabilities of this electron beam machining process. However, the necessity to work in a vacuum system increases the cycle time, comparatively large depth which receives which is something around 100 is to 1, which applications in fine hole drilling are fusible in this process.

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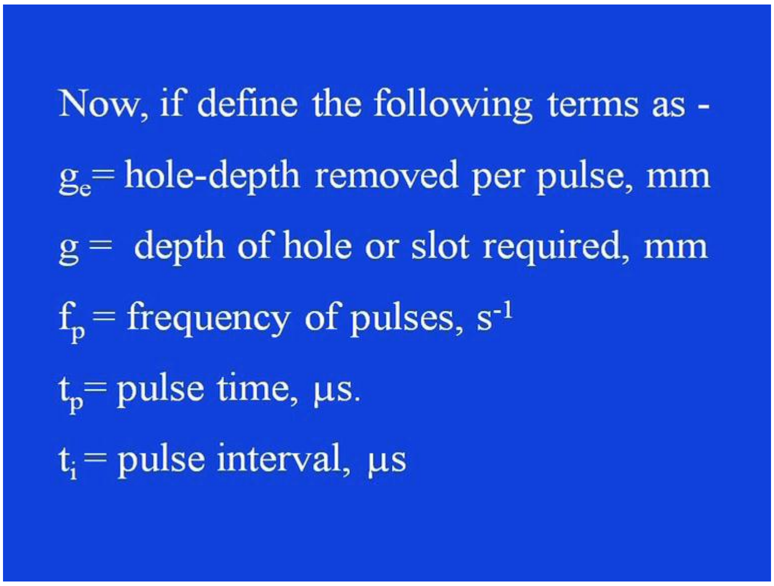

Now, if we define the following terms like g e is the hole depth removed per pulse in millimeter, then g is the depth of the hole or slot required in millimeter, f p is the frequency of pulses per second then t p and t i are the pulse time and pulse intervals in micro seconds. Then the number of pulses required that is n e to remove a hole of depth g, can be described by n e equal to g by g e.

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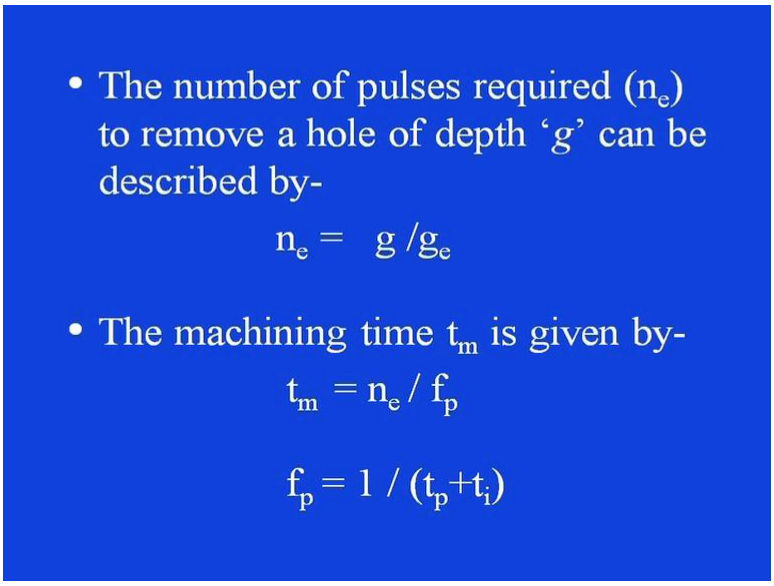

The machining time t m correspondingly is given by t m is equal to n e by f p, where f p is nothing but 1 upon t p plus t i. Hence, the drilling rate phi in millimeter per minute cab be calculated by phi equal to g times f p by n e.

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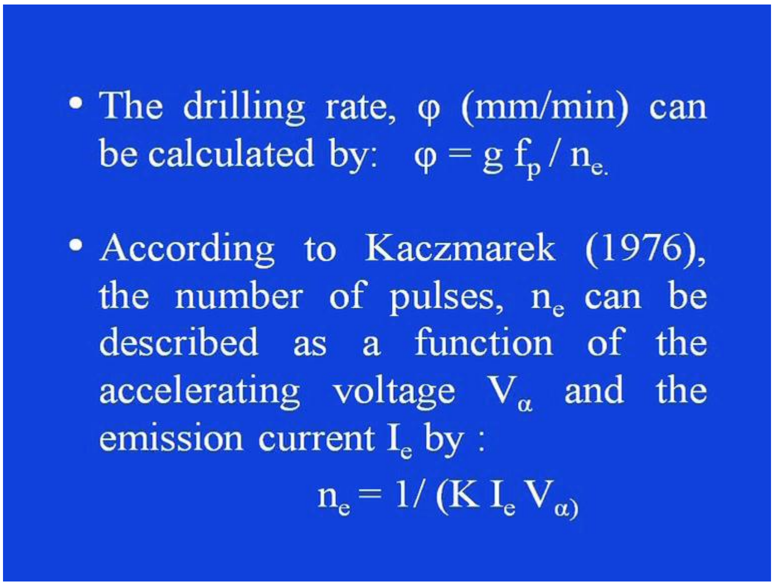

According to Kaczmarek, the number of pulses n e can be described as a function of the accelerating voltage V alpha, and the emission current I e is given by n e equal to 1 upon K times I e into V alpha.

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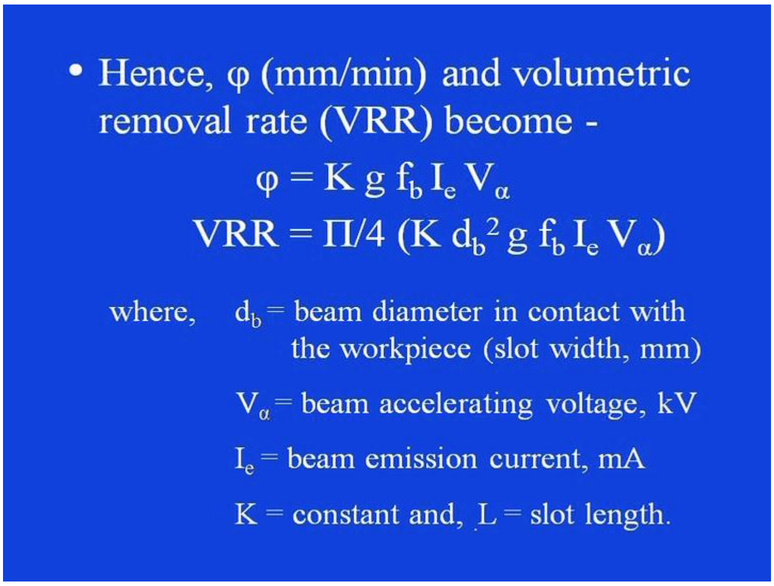

Hence phi in millimeter per minute and the volumetric removal rate V R R become phi is equal to K times g times f b into I e into V alpha whereas, V R R is expressed as pi by 4 in to K times d b square g into f b into I e into V alpha, this is shown in the screen where this d b is nothing but the beam diameter in contact with the work piece, or it can be also considered as the slot width in terms of millimeter. Then V alpha is the beam accelerating voltage which is expressed in kilo volt, I e is the beam emission current which is expressed in mill ampere, and K is a constant where alpha is the slot length.

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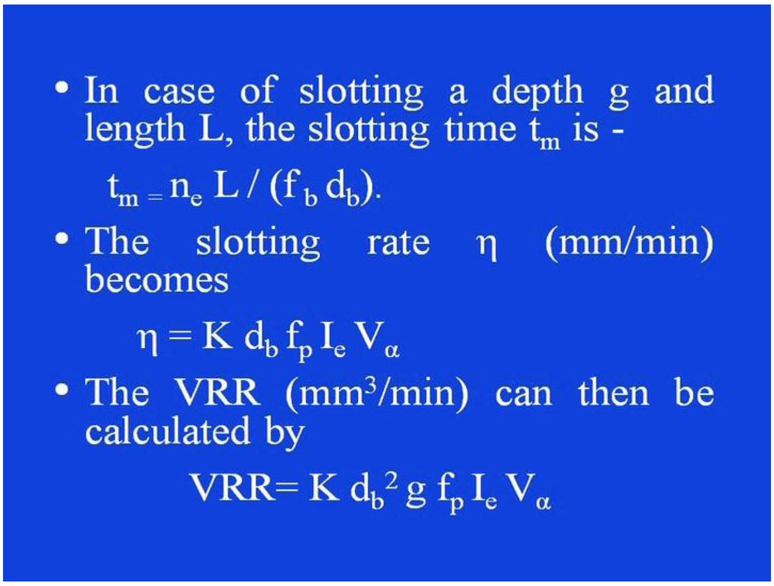

In case of slotting a depth g and length L, the slotting time t m can be expressed as n e into l by f b into d b, then again the slotting rate eta in millimeter per minute can be expressed as K times d b times f b times I e times V alpha, while the volumetric removal rate in millimeter cube per minute can be can be expressed as V R R equal to K times d b square g into f p into I e into V alpha. The depth penetration of the electron beam depends on the beam diameter, power density, and accelerating voltage this we have seen in terms of the mathematical expressions.

The depth of eroded material or pulse on the other hand, depends on the density of the work piece material, as well as on the beam diameter. For a fixed set of process conditions, the number of pulses required increases hyperbolically as the depth of the hole increases. Thus when a certain depth has been reached, any further electron beam machining to depend the hole would require, a very large increase in the number of pulses.

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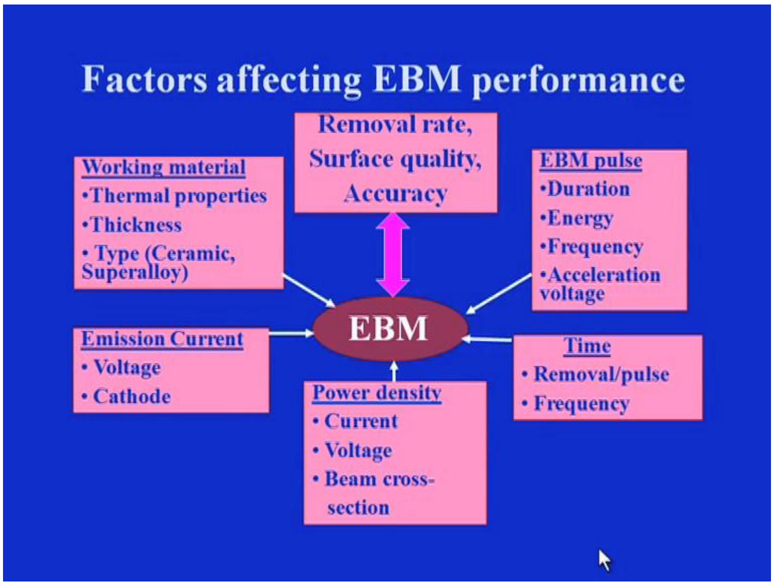

Now, let us see the factors that affect the electron beam machining performance. This factors are generally grouped into these sub headings as shown in the screen, these are work material based parameters in which thermal properties of the material, thickness of the work material and then type of the work material, whether the work material is of ceramic or super alloy etcetera. That influences the material removal rate because the thermal property.

Since, we have already indicated this E B M is a thermal based process, where the material removal takes thus takes place because of the melting, and evaporation of the work material going to the change in the kinetic energy in to thermal energy. Therefore, the thermal properties of the material how fast, the material can acquire heat or get heated depends on will affect the material removal rate, or the performance of the process.

Similarly, as the type of material changes like ceramics, they have got different thermal properties and super alloys, they have got again different thermal properties. Therefore, the time required to get these materials heated, and evaporated will be vastly different and therefore, corresponding performance of the electron beam machining, will be different for different material.

Similarly, another very important group of parameters are the electrical parameters that that is voltage and current. And again the type of cathode that we are using because in this particular machining, the performance of the system depends on the emission of the electron, and this emission of electron will highly dependent on the cathode properties also the different materials will affect, the life of the cathode. Thus the cathode property ultimately influences, the performances of this process.

Similarly, other parameters related to power, applied power are current, voltage and beam cross section, as we have already discussed very high voltage to the tune of 150 kilo volt are being applied between the anode and cathode, which causes the electrons to get emitted. Then the other parameters are time base parameters, that is removal per pulse and the frequency, and then electron beam pulse that is duration of the pulse energy per pulse, frequency and acceleration voltage applied.

This acceleration voltage is another very important parameter, as we have already indicated discussed earlier. This acceleration voltage will be responsible for providing the kinetic energy to the electrons, and the focusing of the beam on to the work piece. So, these parameters ultimately affect the material removal rate, surface quality, accuracy etcetera in electron beam machining process.

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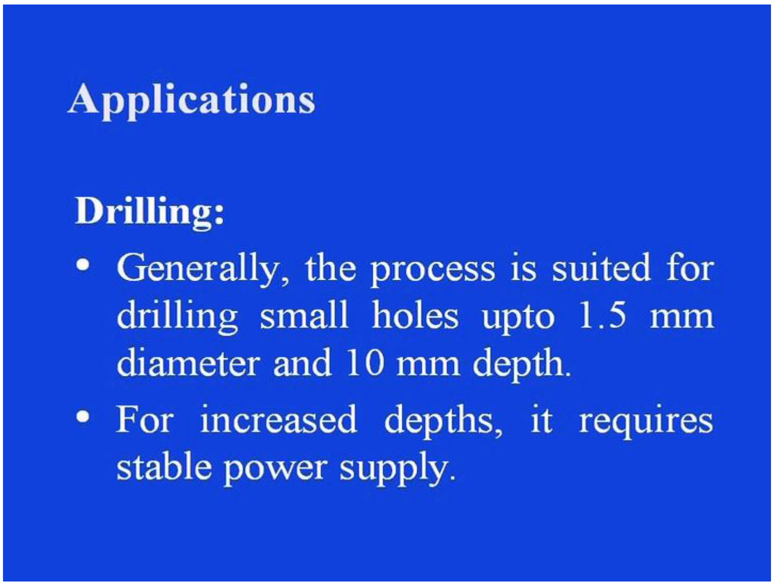

Now, let us see the applications common applications of this particular process. Basically, this process is useful for precision drilling, precision drilling applications generally it is suited for drilling of small holes up to 1.5 millimeter diameter, and the depth wise it can go up to 10 millimeter or so for increase that however, it requires stable power supply, with increased control drills up to 19 mm have been reported. Inclined holes can also be drilled by this electron beam machining process. Perforation of thin sheets can be easily carried out using this E B M.

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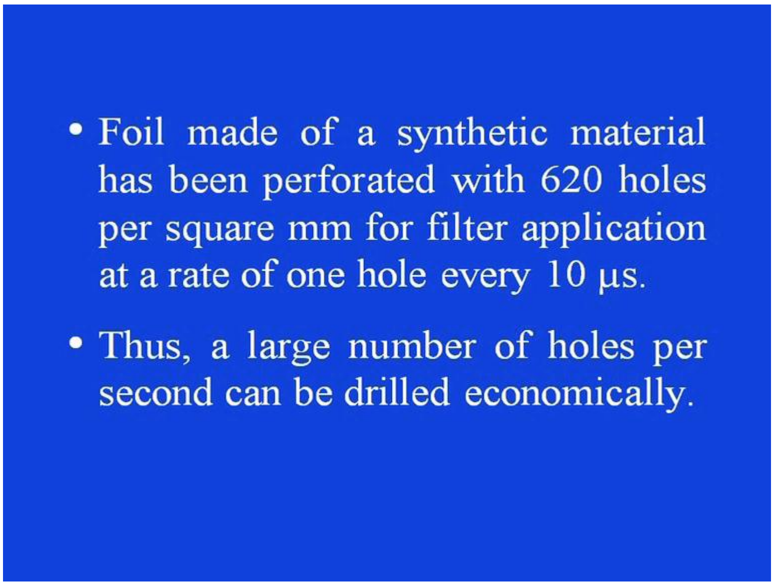

Foil made of synthetic material has been perforated with 620 holes per square millimeter, for filter application at a rate of 1 hole every 10 micro second. This talks about the precision we can have with this particular process, in 1 millimeter 620 holes can be drilled, which is very high as far as the precision the process is concerned. Thus, a large number of holes per second can be drilled very economically.

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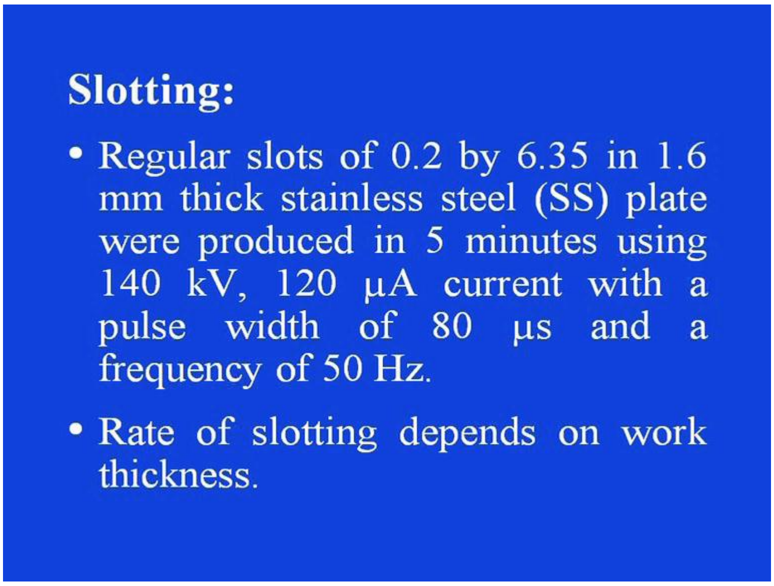

Another application is slotting. Regular slots of 0.2 by 6.35 inches in 1.6 millimeter thick stainless steel, can be produced in 5 minutes using 140 kilo volt 120 micro ampere current, with a pulse width of 80 micro second and a frequency of 50 hertz, this has been reported by researchers rate of slotting depends on of course the work thickness.

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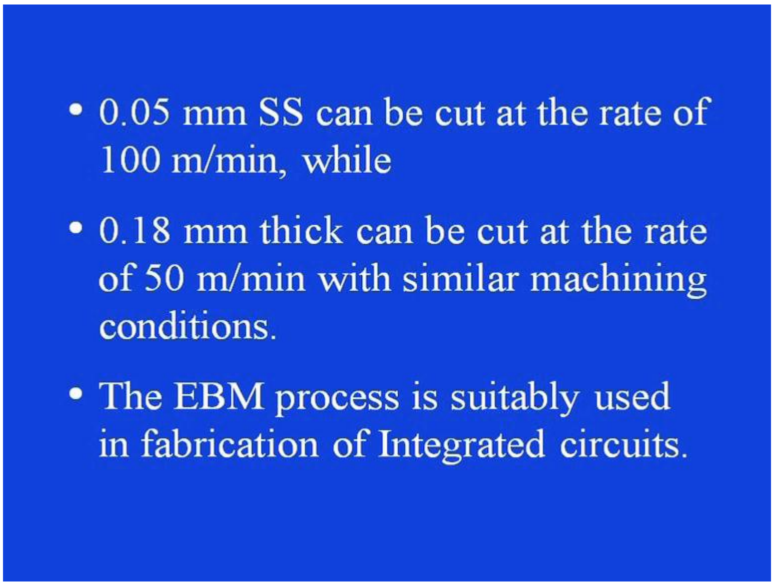

0.05 millimeter stainless steel can be cut at the rate of 100 meter per minute. While 0.18 millimeter thick sheet can be cut at the rate of 50 meter per minute, with similar machining conditions, thus we have seen as the thickness increases the rate of machining comes down significantly. The E B M process is suitably used in fabrication of integrated circuits or I C technology. Other applications of this process include production of filters, and masks of color television tubes for manufacturing sieves in sound insulation, glass fiber productions etcetera.

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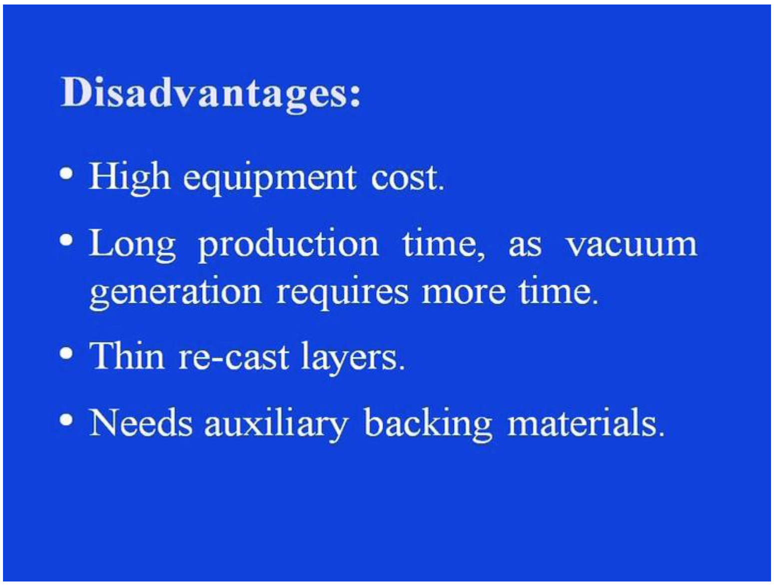

Then let us note few disadvantages of this process also, as I have indicated the very beginning the equipment cost for this process is very high, the production time also relatively very longer. This is basically primarily because of the vacuum generation time, as we have already indicated vacuums to the tune of 10 to the power minus 4 torque are required for effective machining to take place, then as we have indicated this is a thermal base process. So, there will be a thin recast layers as well, then it may need auxiliary backing materials for machining to be performed. Now, let us move on to another precision beam machining technique that is plasma beam machining.

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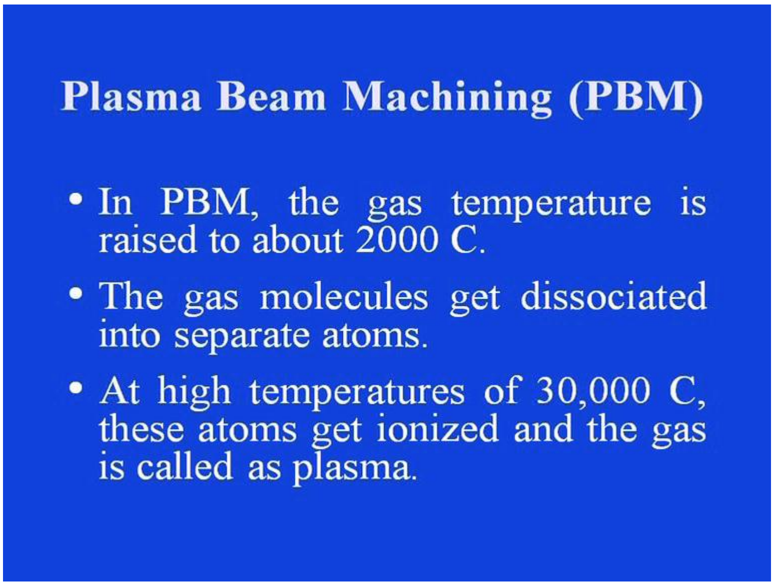

In plasma beam machining, the gas temperature is raised to about 2000 degree celsius. The gas molecules get dissociated into separate atoms, at high temperatures of 30,000 degree celsius, these atoms get ionized and the gas is called as plasma. In the year 1950's plasma was adopted as an alternate to oxy gas flame cutting of stainless steel, aluminum and other non ferrous metals. Recently it is being used for both ferrous, as well as non ferrous metals. The working speed and cutting rate is much faster in plasma beam machining, and the curve produced is also much lower it is very popular for machining stainless steel.

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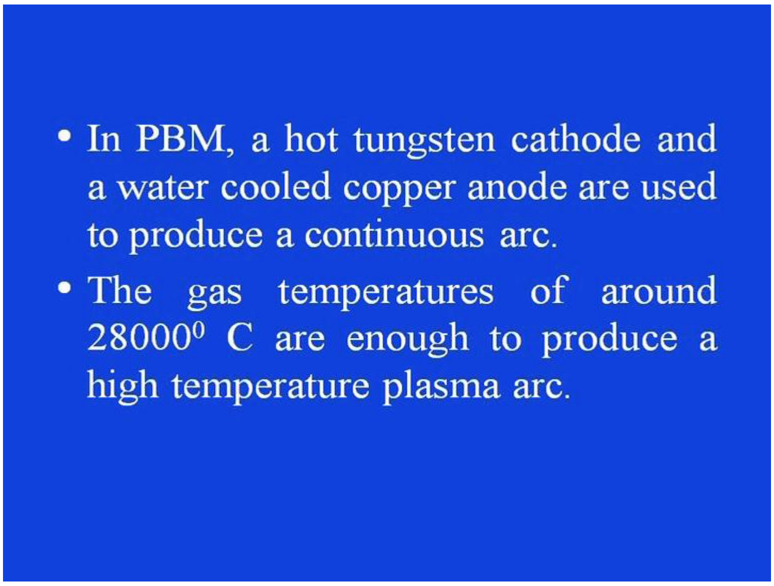

In plasma beam machining a hot tungsten cathode, and a water cooled copper anode are used to produce a continuous arc. The gas temperatures of around 28000 degree celsius are enough to produce a high temperature plasma arc. In this process the material is machined by melting, and evaporation. The general characteristics of plasma beam machining are indicated in this table.

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Table-1 Parameters in PBM

Parameter	Level
Velocity of plasma jet	500 m/s
Material removal rate	150 cm^3/min
Specific energy	100 W/(cm^3.min)
Power range	2-200 kW
Voltage	30-250 V
Current	Up to 600 A
Machining speed	0.1-7.5 m/min
Maximum plate thickness	200 mm

This process velocity of plasma jet is something around 500 meter per second, then material removal rate can be obtained in 150 centimeter square cube per minute, then specific energy is 100 watt per centimeter cube per minute, then power range is between 2 to 200 kilo watt, then voltage applied is 30 to 250 volt, current is very high it could be up to 600 ampere, and machining speed could be 0.1 to 7.5 meter per minute and maximum plate thickness that can be machined could be 200 millimeter. Different types of plasmas are used for machining systems such as plasma arc, plasma jet, shielded plasma and plasma.

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Material removal rate in plasma beam machining is attributed to the plasma torch, which blows away the molten and evaporated metal as a fine spray or vapor. Machining speeds of up to 5 times more than oxy gas cutting can be obtained in fact, this is been reported by different researches. The machining speed is found to decrease with the thickness of the metal or cutting widths. Let us see the accuracy on surface quality that can be obtained in plasma beam machining.

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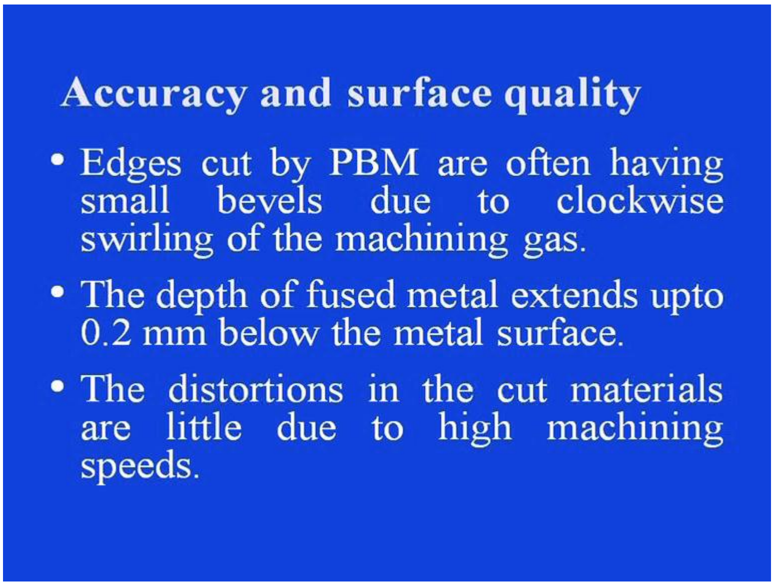

Edges cut by plasma beam machining are often having small bevels, due to clockwise swirling of the machining gas. The depth of fused metal extends up to 0.2 millimeter below the metal surface. The distortions in the cut materials are little due to high machining speeds. So, this process is also a thermal base process, or heat affected zone up to a thickness of 0.25 to 1.2 millimeter are reported. Clean smooth surfaces are produced, in plasma with very few micro packs below the heat affected zone, materials can generally be cut with in a tolerance rate of plus minus 1.6 millimeter.

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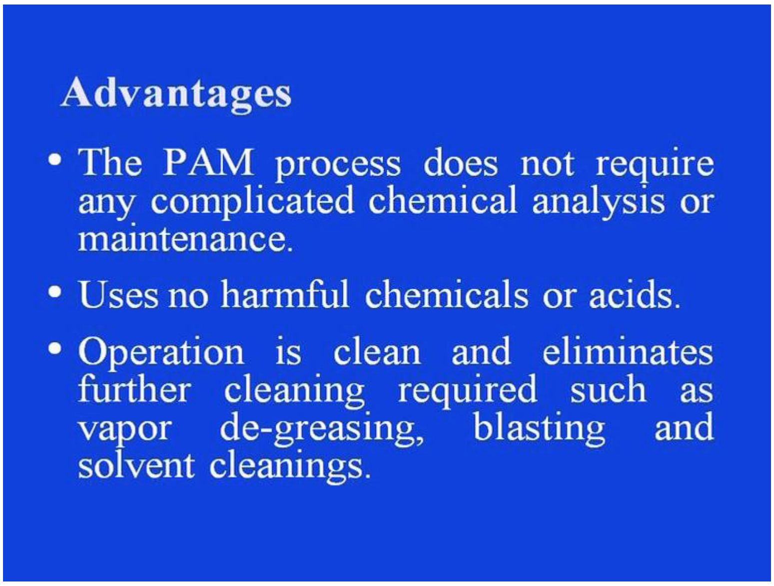

Let us quickly look at the advantages of this process, the plasma beam machining processes does not require any complicated chemical analysis, or maintenance. The process uses no harmful chemicals or acids. Operation is clean and eliminates further cleaning required such as vapor de-greasing, blasting and solvent cleanings thus such the operation is clean.

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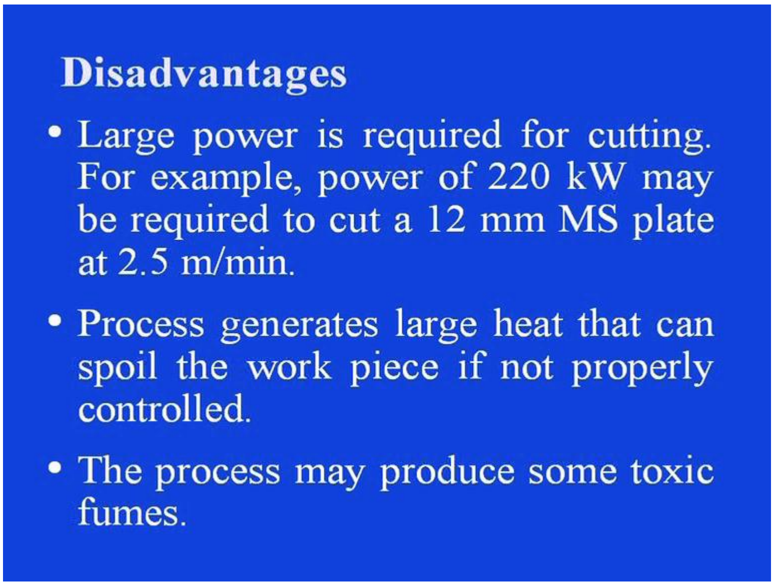

There are few disadvantages as well, the first one is the large power is required for cutting. For example, power of 220 kilo watt may be required to cut a 12 millimeter M S plate, mild steel plate at 2.5 meter per minute which is quite high. Process generates large heat that can spoil the work piece if not properly controlled. The process may also produce some toxic fumes. Now, let us look at the applications of this process.

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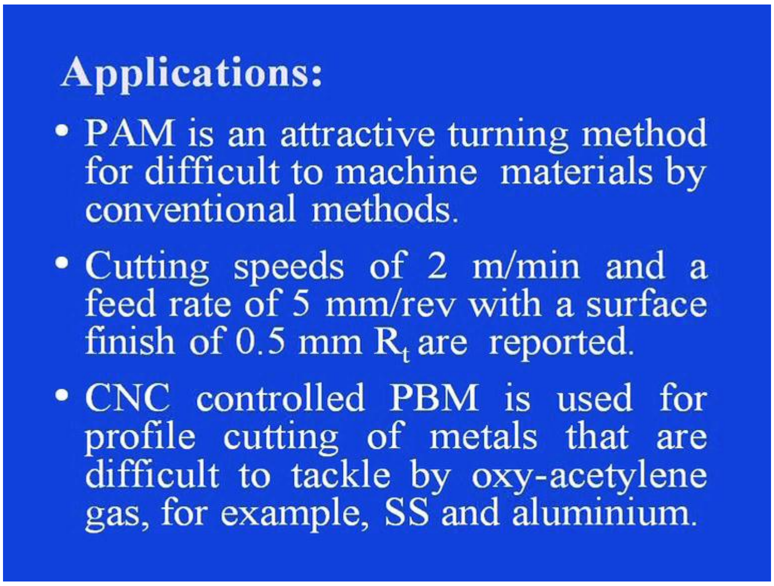

Plasma arc machining is an attractive turning method by conventional methods. Cutting speeds of 2 meter per minute and a feed rate of 5 millimeter per revolution, with a surface finish of 0.5 millimeter R t are reported. Computer numerical controlled plasma beam machining is used for profile cutting of metals that are difficult to tackle by oxy-acetylene gas, for example stainless steel and aluminum. Plasma beam machining is used to cut groups in stainless steel, the process is also recommended for parts that have subsequent building operations. Under water numerical control plasma are also used with higher machining accuracies of plus minus 0.2 millimeter in 9 meter at a lower cutting speed.

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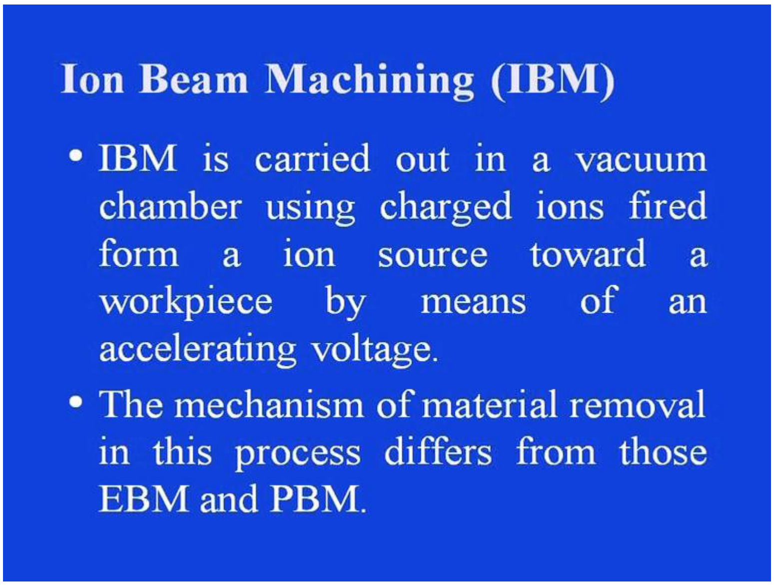

Now, let us move on to another precision beam machining technique, that is iron beam machining, in short it is known as I B M. Iron beam machining is carried out in a vacuum chamber, using charged ions fired from a ion source towards a work piece by means of an accelerating voltage. The mechanism of material removal in this process differs from those in E B M and P B M that is electron beam machining, and plasma beam machining. In ion beam machining the atoms are ejected from the surface by other ionized atoms, which bomber the work materials. Accordingly this process is also known as ion itching, ion milling, or iron polishing.

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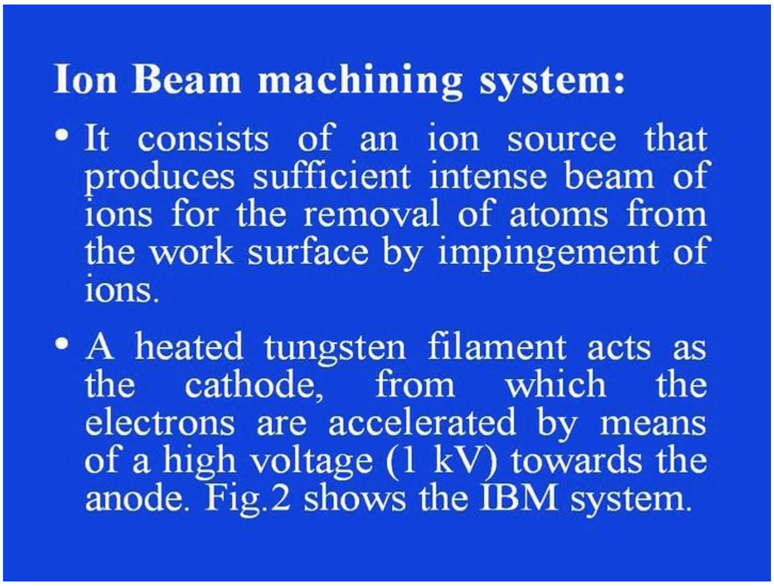

Now, let us look at the ion beam machining system. The system consists of an ion source that produces sufficient intense beam of ions, for the removal of atoms from the work surface by impingement of ions. A heated tungsten filament acts as the cathode from which the electrons are accelerated by means of a high voltage, which is around 1 kilo volt towards the anode.

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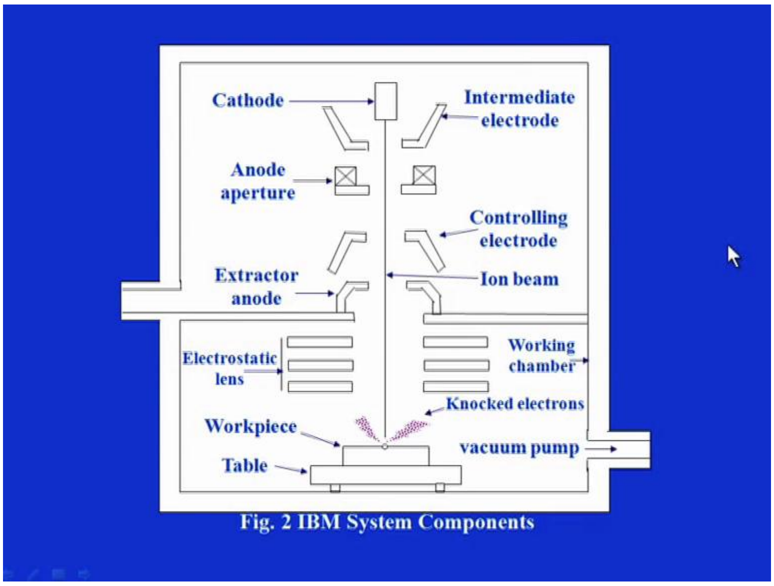

Fig. 2 IBM System Components

This figure shows this process, in which the, this schematic is in the screen in which this is the cathode, which will be responsible for emitting the electrons. And there will be some intermediate electrodes and of course, there will be an anode to which this electrons will be attracted. However, there will be controlling electrodes, which will guide these electrons speeding electrons, towards the work piece and this will hit the work piece at a particular point, in which instead of heating mechanism the atoms will be removed or ejected because of the heating of the atoms or ions on this work piece.

Therefore, this is rather than thermal process, in which melting and evaporation does take place in case of electron beam machining, and plasma beam machining here atoms will be removed or ejected out because of the heating of this ions on this work, work piece surface. As we have already indicated, the process also needs high vacuum and therefore, the entire chamber will be connected to a vacuum pump.

There will be again electro static lens, lens systems which will in fact guide or control the beam of this ions on to the work piece. During the passage of these electrons from the cathodes towards the anode, they interact with argon atoms in the plasma source to produce the argon ions. A magnetic field is produced between the cathode, and the anode which makes the electrons spiral. The produced ions are then extracted from the plasma towards the work piece, which is mounted on a water cooled table. So, this can be explained like this.

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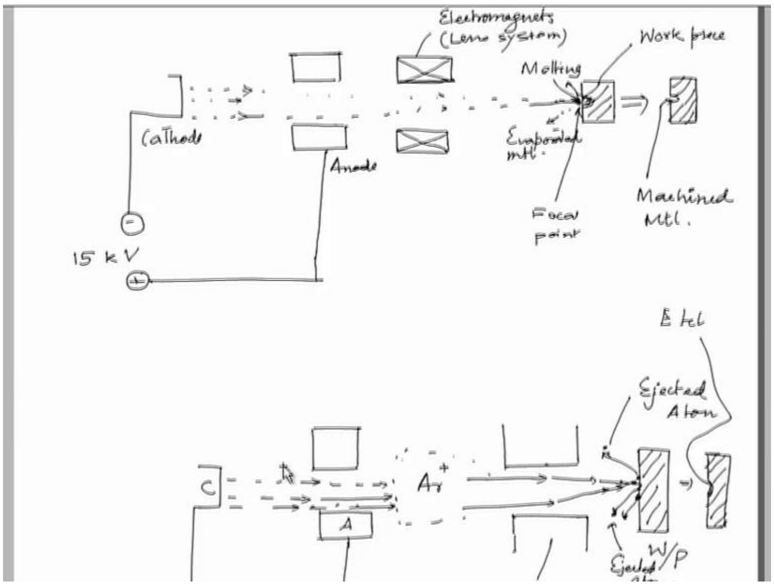

In this process again there will be a cathode. So, this is c is cathode, and there will be an anode system say anode system, which will be connected to the anode of the power supply. So, this will be the power and therefore, the electrons will be attracted towards this anode, this is anode. Now, in between there will be argon gases, argon gases we can say so this is A r gas and this argon gas will be ionized by this high moving electrons, and the argon ions will be now, this argon ions will be focused or accelerated towards a particular point, or a focal point which is nothing but the surface of the work piece material.

So, this is nothing but the work piece material, this is done by a special mechanism of fields or you we can say electrostatic fields, this is electrostatic field for controlling the beam, beam of ions. Thus this beam of when this beam of ions hit this work piece surface, atoms of the small atoms of this surface will come out from this surface work piece surface.

Therefore, these are ejected we can say these are ejected atoms rather than the evaporated materials, evaporated materials as in the case of P A M or E B M. So, these are nothing but ejected atoms, ejected atoms and this will ultimately cause the machining of the work piece material, where the beam exactly hit the material work piece material. So, this will look like this is also called etching. The machining variables, which can be independently controlled or the acceleration voltage, flux and the angle of incidence.

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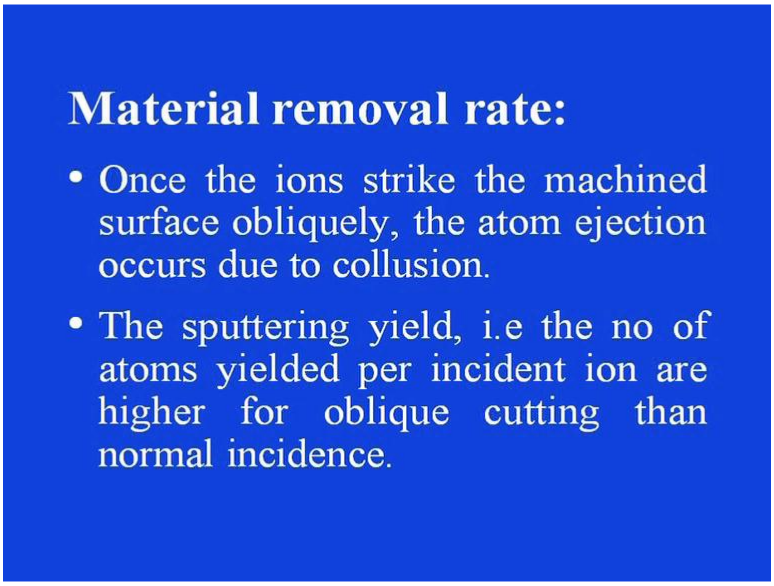

Let us look at a material removal rate in this process, once the ions strike the machined surface obliquely, the atom ejection occurs due to the collusion. The sputtering yield that is the number of atoms yielded per incident ion are higher for oblique cutting, than normal incidence. The material is removed by transfer of momentum from the incident ions, to the atoms on the surface of the material. The atoms removed from the surface are reflected away from the material. Energies greater than binding energy of 5 to 10 electron volt are needed to effect the removal of atoms.

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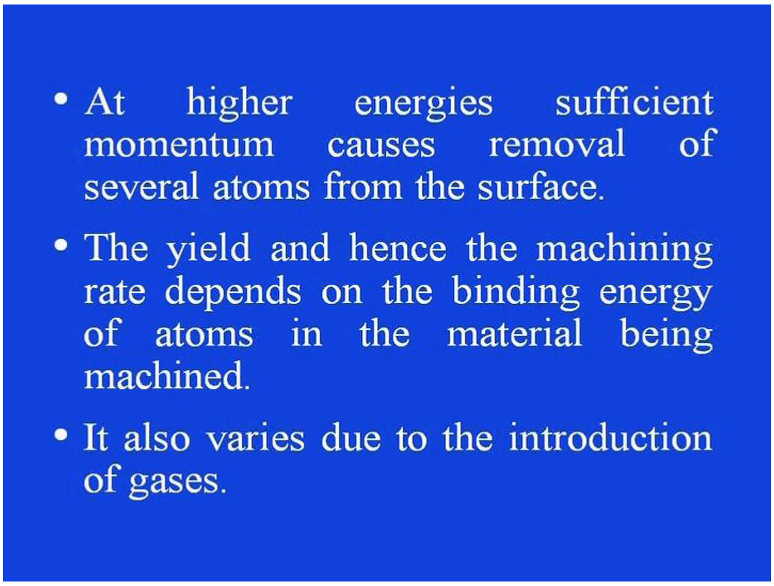

At higher energies sufficient momentum causes removal of several atoms from the surface. The yield and hence, the machining rate depends on the binding energy of atoms, in the material being machined. It also varies due to the introduction of gases. The etch rate v theta in atoms per minute is given by.

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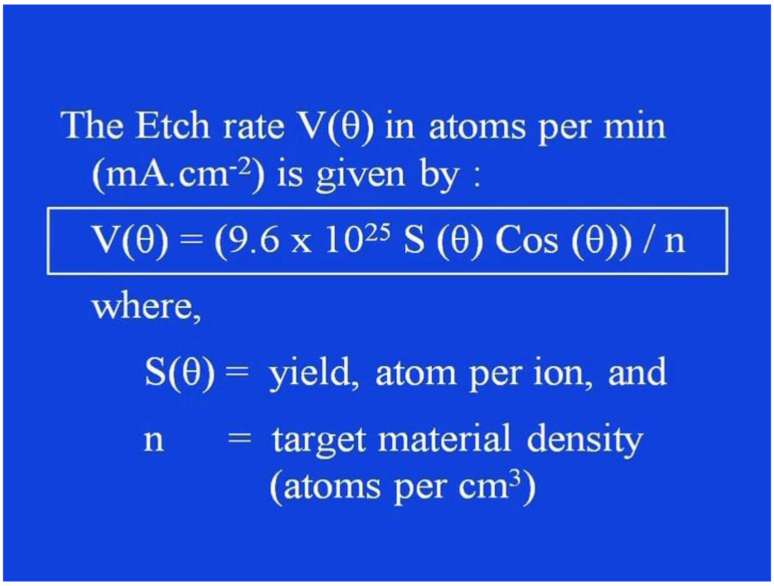
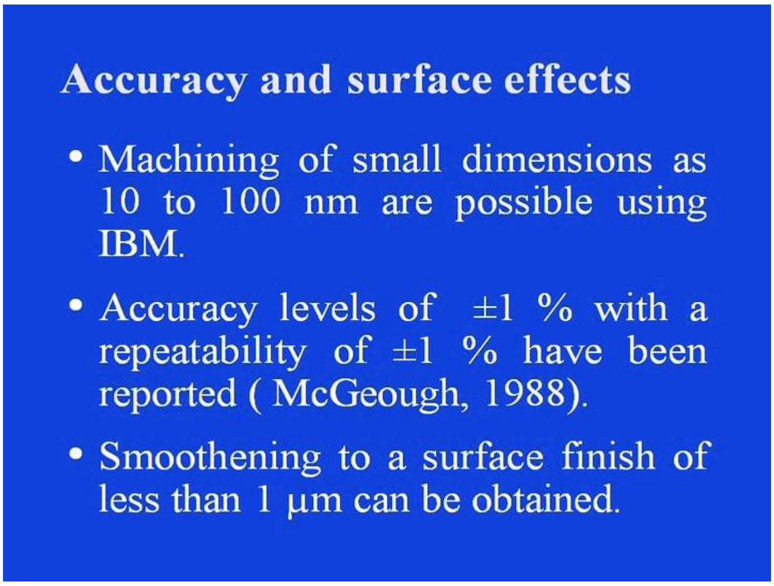


As can be seen in the screen 9.6 into 10 to the power 25 S theta into cos theta divided by n, where S theta is nothing but the yield in terms of atoms per ion, and small n is the target material density, which is atoms per centimeter cube. Then let us see about the accuracy in the surface effects of this ion beam machining.



Machining of small dimensions as 10 to 100 nanometer are possible, using this ion beam machining accuracy levels of plus minus 1 percent with repeatability of plus minus 1 percent have been reported. Smoothening to a surface finish of less than 1 micro meter can be obtained. Let us look at the applications of this process, the I B M process is used in smoothening of laser mirrors as well as, reducing the thickness of thin films without effecting the surface finish, in this regard thinning of samples of silicon to a thickness of 10 to 15 micrometer have been reported, using argon ions impinging at normal incidence by MC Geough in the year 1988.

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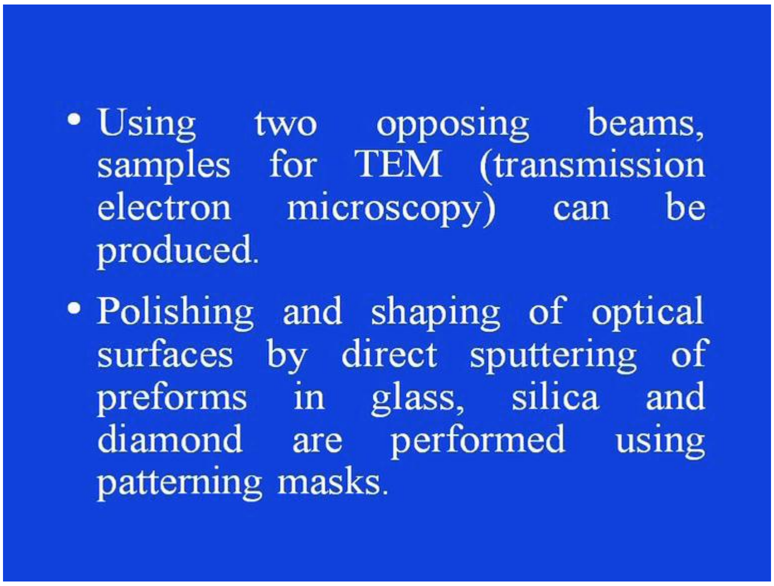

Using two opposing beams, samples for transmission electron microscopy can be produced. This is a very critical application because the sample preparation for transmission electron microscope is a critical job, which needs very thin samples to be prepared. Polishing and shaping of optical surfaces by direct sputtering of performs in glass, silica and diamond can be performed using patterning masks.

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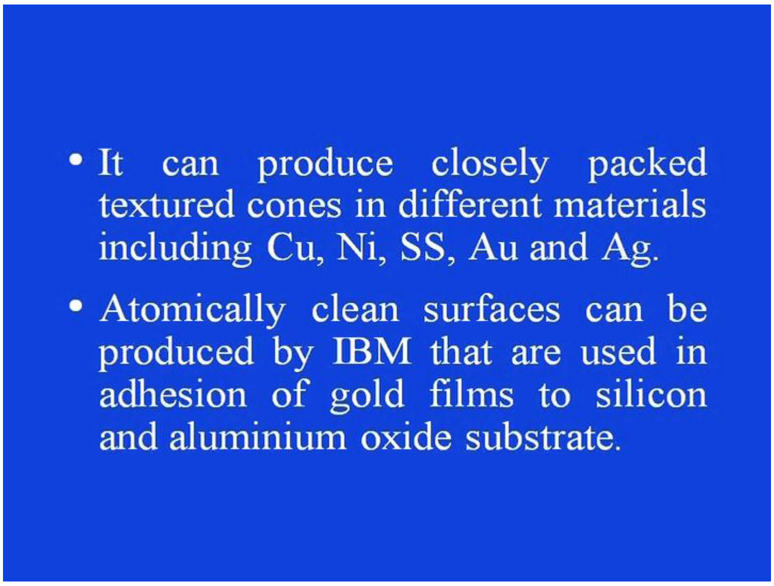

The process can produce closely packed, textured cones in different materials including copper, nickel, stainless steel, gold and silver. Atomically clean surfaces can be produced by I B M process, that are used in adhesion of gold films to silicon, and aluminum oxide substrates. Layers of surface oxide can be removed by using higher ion energies. Ion beam machining can mill a line width of 0.2 micrometer, which is used in fabrication of bubble memory devises of depth to width ratios up to is to 1.

Now, let us summarize what we have discussed in this session. In this session we have discussed three more advanced manufacturing processes namely, electron beam machining, plasma beam machining, and ion beam machining. The principles of operations of each processes have been discussed, the setups have been discussed and some unique advantages, and limitations as well as applications of all the three processes have also been discussed. We hope this session was informative, and interesting.

Thank you.