Advanced Machining Processes

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Module - 07
Lecture - 17
Electron Beam Machining (EBM) Edit Lesson

Welcome to the course on electron beam machining process. Today we are going to discuss on electron beam machining. In electron beam machining process there is a bombardment of high velocity stream of electrons on the workpiece surface so this electrons are bombarded on the workpiece surface with a very high velocity, around 66% velocity of the sunlight so because of this bombardment of electrons on the workpiece surface the materials into a small area on the workpiece surface it melts and vaporizes and temperature rises to a very high temperature. So material on the workpiece surface melts and vaporizes and machining is going on.

So this process actually it is used for machining thousands of holes on a thin sheet which is used in aerospace industry, food processing industry, cloth industries and very high aspect ratio for making of very high aspect ratio holes, thousands of holes on a workpiece surface irrespective of the material property like metallurgical property, mechanical property of the material.

So this material maybe electrically conducting or electrically non-conducting or maybe ceramics, metals, or any kind of metal, any kind of ceramics it works. So here there is a filament which is heated with a very high temperature. So because of this heating of this filament so electrons emanates from that cathode, cathode filament or these filament may be heated from a radiation from a another body, from the radiation from a another body on a solid block of cathode, on a solid block of filament also it can be generated. So these electrons emits from the cathode, cathode filament and it passes through a magnetic lens to coincide to concentrate or to reduce the diameter of the electron beam and it bombards on the workpiece surface.

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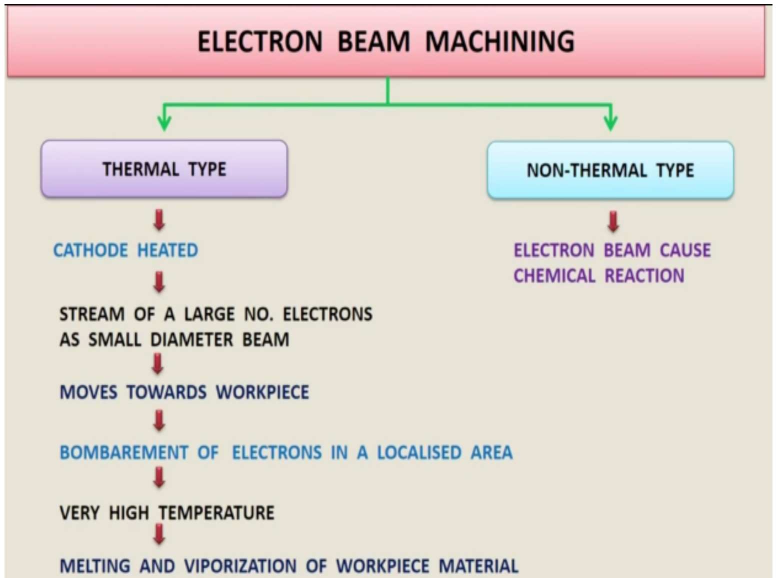

So electron beam machining process there are 2 types of methods are there. One is the thermal type. Another one is the non-thermal type. So in normal in non-thermal type this electron beams are used for generating chemical reactions. So for generating chemical reactions the electron beams are used. So this non-thermal type we are not going to discuss. We are going to discuss only thermal type of electron beam machining process. In thermal type this cathode is heated to a very high temperature. So this stream of large number of electrons comes as a small diameter beam, electron beam.

So this stream of large number of electrons emits from the cathode, from a heated cathode. It comes out as a small diameter beam. So it moves towards the workpiece with a very high velocity and it bombards, machining is going on due to the bombardment of this electrons on a very small localized area. So as it is bombarded on a very small localized area, huge amount of temperature is generated on the workpiece surface. So machining is going on due to the melting and vaporization of this material from the workpiece surface from a very localized area.

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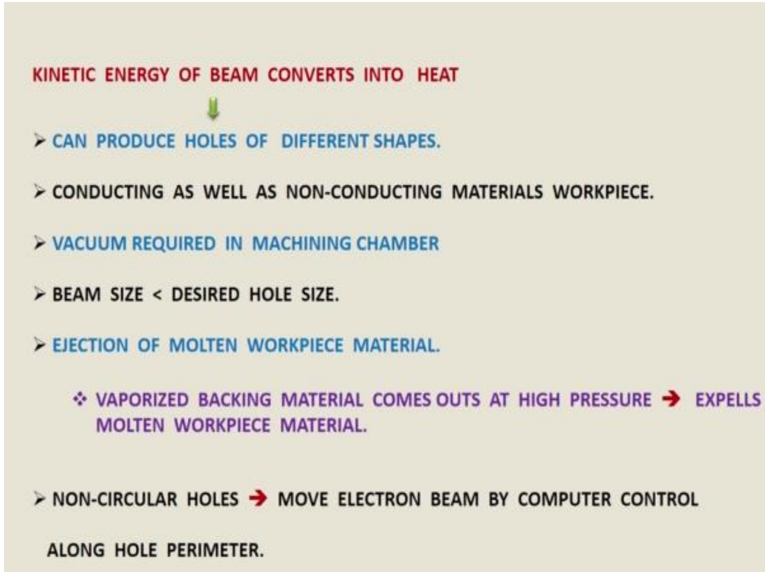

So this kinetic energy of this electron beam is used for the machining to take place and which converts this kinetic energy of the beam, electron beam high velocity electron beam, converts into the heat energy. So it can produce holes of different shapes. So any kind of shapes other than circular also can be generated by deflecting the beam at certain angle. So workpiece material can be conducting as well as non-conducting, any kind of workpiece material can be machined irrespective of their hardness, mechanical and metallurgical properties can be machined by this process. Also another thing is that vacuum is required.

So this machining chamber should be vacuum chamber because this electron beams when it when it travels so if air is there into the chamber so it will collide on the air molecules. So its strength will be reduces. So that is why this vacuum is generated into the machining chamber. Also this cathode it is used as a tungsten cathode is used if air is there so it will immediately it will be oxidized. So to reduce or to avoid the oxidation of this tungsten filament cathode so this vacuum chamber is used. So beam size, this diameter of this beam size should be less than the diameter of the hole to be produced.

So ejection of the molten material, how this molten material is ejected or molten or vaporized material is ejected from the workpiece surface, so at the back side of the workpiece backing material is used. So after machining on the top surface of the workpiece so when it reaches to the bottom side of the workpiece it also vaporizes the backing material. So this backing materials also vaporizes so it comes out as a high pressure. So this backing materials it comes out as a very high pressure so while coming as a high pressure it also ejects the molten or vaporized material on the workpiece surface. So it expels the molten or vaporized material from the workpiece surface so at the back side of the workpiece surface there is a backing material is used. So that is why this backing material is used.

So non-circular holes also can be generated by electron beam machining process. Any kind of shape, any shape, any kind of shape of the workpiece can be generated by this electron beam machining process. So you can make a you can keep a fixed beam and you can travel the workpiece on a computer numerical CNC table. You can place your workpiece on a CNC table and you can generate any kind of complex shape or you can move the beam on the workpiece surface using a CNC table. So in both the way you can generate any kind of non-circular holes on the workpiece surface. So circular big holes can be generated. You can move the beam along the perimeter of the circle so you can generate the bigger size holes also.

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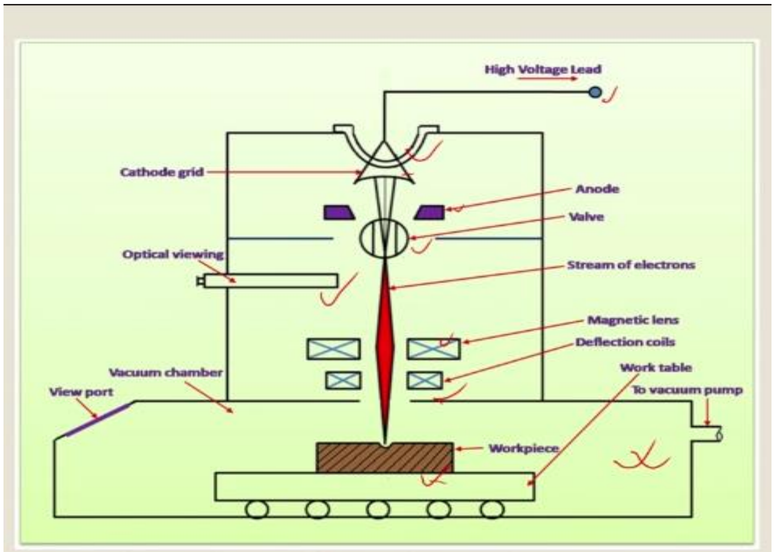

Fig. Schematic diagram of electron beam machining system.

So this is the schematic diagram of the electron beam machining process. You can see here, this is the cathode. So you can see here this is the cathode here. So this cathode filament it is actually heated up by using a high voltage lid. So there is a high voltage lid is there. So using this high voltage lid this cathode is actually heated up. So this electron beams, streams of electrons are coming outside from the cathode filament because of the repulsive force from the cathode.

So electrons are negatively charged or here this cathode also they are negative terminal of the power supply. So this electrons are expelled with a very high velocity and it is coming towards the anode. So it is attracted towards the anode here, so this is anode. So as it is attracted towards the anode and it is also expelled by the cathode, so it generates a very high velocity. So it is around 66% of the light, velocity of light. So it is passed through a valve coil. This whatever the stray electrons are there it is actually filtered, the stray electrons are filtered through this valve and you can see this one this what is happening inside this vacuum chamber so you can see using this optical viewing system.

Now this electron beams is passing through the magnetic lens. So this is the magnetic lens. The working principle of this magnetic lens is that so it actually concentrates all the beam into a certain point. So it reduces the diameter of the electron beam passing towards the workpiece so it concentrate into a smaller diameter beam. So after that it passes through a deflection coil and after doing after passing through this deflection coil it falls on the workpiece surface into a very small area.

So when it falls on the workpiece surface into a very small area so into that area into that small area so because of this bombardment of high velocity electrons it melts and vaporizes the material and at the back side of the workpiece this chemical backing material is used so when these holes actually extended towards the end of the workpiece this backing materials also because of heating this high velocity gases are generated so this gas when it is coming outside with a very high pressure it expels whatever the molten material is there at the at the hole whatever this molten material it also expels the molten material.

So whatever this recast layer, whatever this molten material whatever it is redeposited on the workpiece surface this recast layer is can be reduced by this chemical backing material. So this entire chamber it is actually made vacuum to reduce the possible collision of the electrons with the air molecules.

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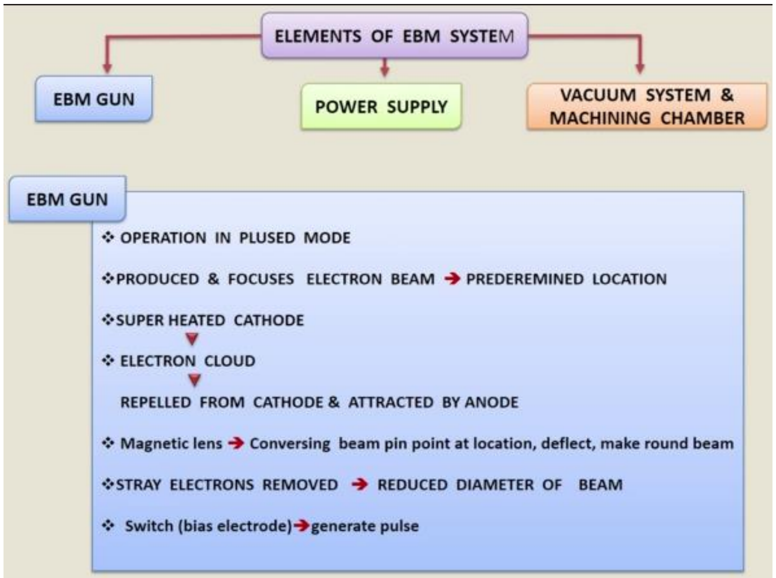

So here you can see there are different elements of electron beam machining system. First one is the electron beam gun, electron beam gun and second one is the power supply and third one is the vacuum system and the machining chamber. So electron beam gun so it operates in the pulse mode. So there are some biased electrodes are used. So by controlling this electrode you can generate the electron beam, so pulse electron beam you can generate.

So it electron beam gun produce focused electron beam on a predetermined location. So there is a superheated cathode is there. It usually it is a tungsten filament which is heated up with a very high temperature or you can use a solid block of cathode which is heated up by the radiation of a filament. So both things are possible. So because of this heating up this cathode electron clouds are actually generated surrounding the cathode.

So this electron clouds because of this these are negative charged it is expelled because of the repulsive force of the cathode from the cathode and it is attracted by the anode. It is attracted by the opposite charge anode and then after that it passes through the magnetic lens. So when it is passes through the magnetic lens so a converging beam pinpoint at a location can be generated.

So this beam is actually pinpointed into a small location when it is passes through a magnetic lens and also it deflates and make a round beam. So this is the working principle of this magnetic lens. So also this stray electrons are removed through the by using this magnetic lens and the diameter of the beam is further reduced. So this switch it passes through a switch or biased electrode to generate the pulse.

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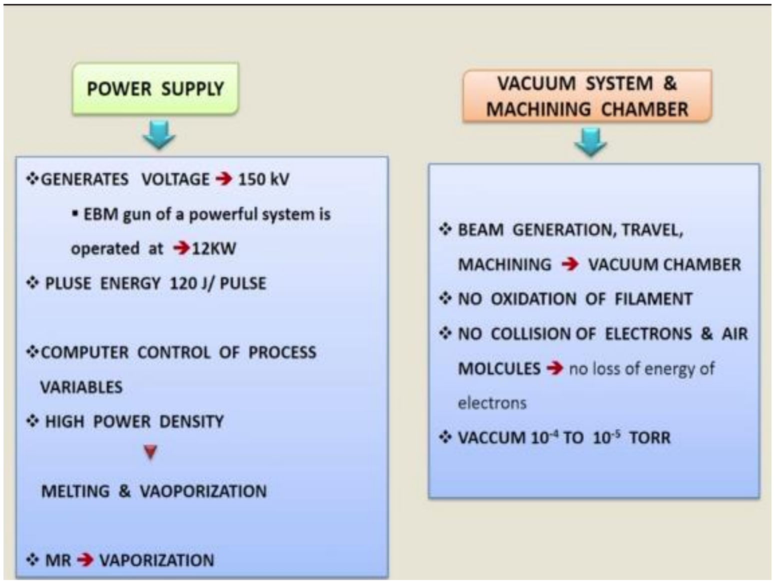

So this power supply it generates a high voltage. So it is around 150 kV. Because of this high voltage electron beam gun generates the electrons. So this electron beam electron beam machining gun is a powerful system. It is operated at 12 KW. Pulse energy as high as 120 J/pulse power pulse can be generated from this electron beam machining gun. So computer control of the process variables can be generated. So all these parameters are controlled from a computer.

So high power density is required for melting and vaporization of the material and it will give the high material removal rate also and as the huge amount of energy by the collision of this electrons are generated so material is machined mostly by vaporization of this material. Now this vacuum system and machining chamber, already I told this machining chamber is vacuum, as the beam actually travels during machining so it may collide with the air molecules so that is why to avoid the collision of this electron beams with the electron with the air molecules so this machining chamber is made vacuum. So the pressure inside this machining chamber is maintained 10 to the power minus 4 to 10 to the power minus 6 torr.

So because of this vacuum so there is no oxidation of this tungsten filament otherwise if it is not vacuum so whatever this oxygen molecules are there inside the air it will oxidize the tungsten filament so which is heated up to a very high temperature. So there is no collision of this electrons and the air molecules and no loss of energy of this electrons because of this vacuum chamber.

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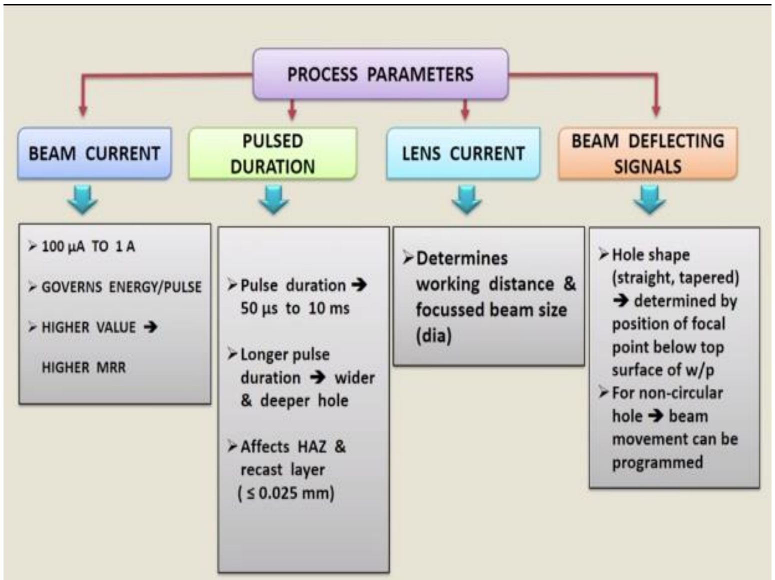

Now what are the different process parameters for this electron beam machining process. So this process parameters are beam current, pulse duration, duration of this pulse as I told the electron beam machining system this machining is going on by the pulse mode not in the continuous mode. So lens current, current to the lens, magnetic lens and then beams deflection deflecting signals. So these are the 4 parameters, 4 important parameters for electron beam machining process.

So this beam current it maybe it varies from 100 microampere to 1 ampere. So this beam current actually governs what is the energy per pulse. It governs the energy, beam energy per pulse on the workpiece surface. Higher value of this beam current will generate high beam energy per pulse and it will generate the high material removal rate. So by changing this beam current you can change the beam energy or you can change the material removal rate on the workpiece surface.

Now pulse duration, this duration of this pulse varies from 50 microsecond to 10 millisecond. So longer pulse duration will generate wider and deeper holes. So if we put this pulse on a for a longer duration of time on the workpiece surface so obviously it will generate a wider shallow hole but deeper holes because it is kept on the workpiece surface at a certain time for a longer period of time. So it will generate wider and deeper holes and it affects this pulse duration also affects the heat affected zone on the workpiece surface because of this heating of this surrounding materials it generates a higher heat affected zone if this pulse duration is increased.

So this recast layer the dimension of the recast layer in case of electron beam machining process is 25 micron around 25 micron.

Now lens current, it determines the working distance and focused beam size. So beam diameter it determines the lens current determines the beam diameter and also it determines the working distance and also it determine the what is the diameter of the beam. So beam deflecting signals it affects the hole shape straight or tapered hole determined by the position of the focal point below the top surface of the workpiece.

This holes whether it will be straight or tapered it depends on the this focal position focal point of the beam whether it is just top surface of the workpiece or just below the workpiece surface. For noncircular hole beam movement can be programmed. So other than circular other than circular hole this beam movement can be programmed.

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$MRR = \eta\ (P/W)$ **(Rate at which w/p material vaporized)**

WHERE, η IS CUTTING EFFICIENCY (usually below 20%),

P IS POWER (J/S),

W IS SPECIFIC ENERGY (J/cm^3) required to vaporize work-material

$$W = C_{P_S}(T_M - T_i) + C_{P_l}(T_B - T_M) + H_F + H_V$$

WHERE, C_p → Specific heat,

T_M → melting point temperature,

T_B → boiling point temperature

H_F → latent heat of fusion

H_V → latent heat of vaporization

Here, C_p is assumed to be constant although it varies with temperature. Suffix **S** and **L** indicate solid and liquid states, respectively.

Now this material removal rate it is calculated as eta P by W. So material removal rate in case of electron beam machining process it is calculated from eta P by W where material removal rate is rate at which material workpiece material is vaporized. So eta is the cutting efficiency. It is around 20% or less than 20% in case of electron beam machining process. P is the power in J/S and W is the specific energy J/cm cube required to vaporize the workpiece material or W is the energy specific energy required joule per J/cm cube to vaporize the workpiece material.

Now this W can be calculated as C PS TM minus Ti. CP is the specific heat, TM is the melting point temperature of the workpiece material minus Ti, Ti is the initial temperature of the workpiece plus C Pl, C Pl is the specific heat, TB minus TM, TB is the boiling point temperature of the workpiece material minus TM is the melting point temperature of the workpiece material plus HF plus HV. HF is the latent heat of fusion and HV is the latent heat of vaporization and this S and l C PS is the specific heat of the solid and C Pl specific heat in liquid. So CP is assumed to be constant although it varies with the temperature but it is assumed to be constant and suffix S and L indicate the solid and liquid states respectively. So from this equation MRR can be calculated eta into P by W, P is the power and W is the energy required per volume per unit volume of the workpiece.

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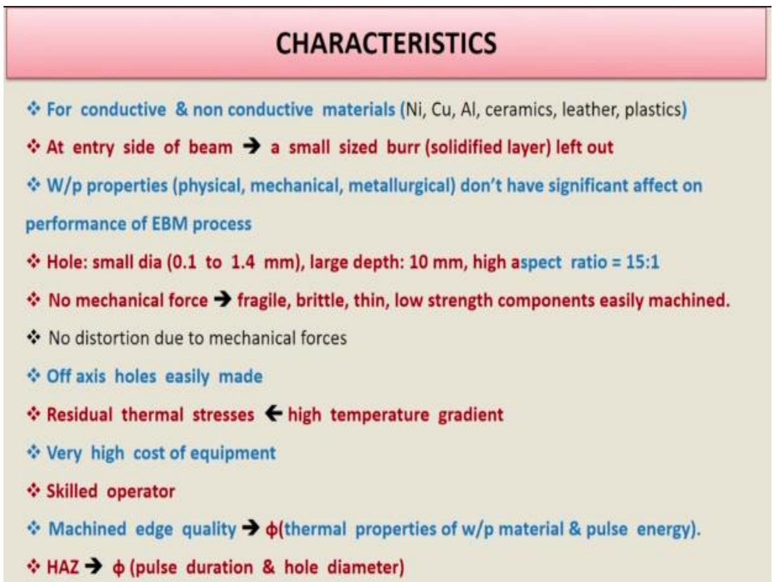

Now process characteristics electron beam machining process characteristics, so it can be used for conducting as well as non-conducting material like nickel, copper, aluminium, ceramics, leather, plastics. So any kind of material can be machined by this process. So at the entry side of the beam it is observed that there is a burr. Because this recast layer or vaporized materials are coming outside, vaporized while this vaporized materials are coming outside, so it actually generates a recast layer at the entry side also.

So this because of this recast layer small amount of burrs are actually visible at the entry side of the workpiece. So this at the entry side of the beam a small sized burr solidified layer left out. So workpiece properties physical, mechanical, and metallurgical properties do not have significant effect on performance of the electron beam machining process. So workpiece properties does not have any effect on the performance of the electron beam machining process.

Hole diameter as low as 0.1 to 1.4 mm and large depth 10 mm and high aspect ratio of 15:1 can be generated from the workpiece surface. So there is no mechanical force because this electron beam machining process this tool does not touch the workpiece surface so there is no mechanical force. So any kind of thin and fragile materials can be machined, low strength components can be machined, easily machined by this process.

So hence as there is no workpiece tool material does not touch the workpiece surface. There is no distortion of the workpiece due to the mechanical forces. Off axis holes also can be easily generated by deflecting the beams but there is a thermal residual stress is generated because there is a huge temperature gradient is there because there is a huge amount of temperature is generated locally at the on the workpiece surface where this beam falls.

So there is a huge temperature gradient is there so because of this temperature gradient thermal residual stress is generated by electron beam machined surface. One disadvantage of this process is there. Cost of equipment is very high. So this electron beam machining cost, equipment cost is very high and also it requires skilled operator to machine on the workpiece surface and machine edge quality depends on the thermal properties of the workpiece material and pulse energy, how much pulse you are giving, how much energy you are giving per pulse also affects the quality of the machine edge. Heat affected zone in case of electron beam machining process depends on the pulse duration and the hole diameter. So this heat affected zone depends on the pulse duration and the hole diameter.

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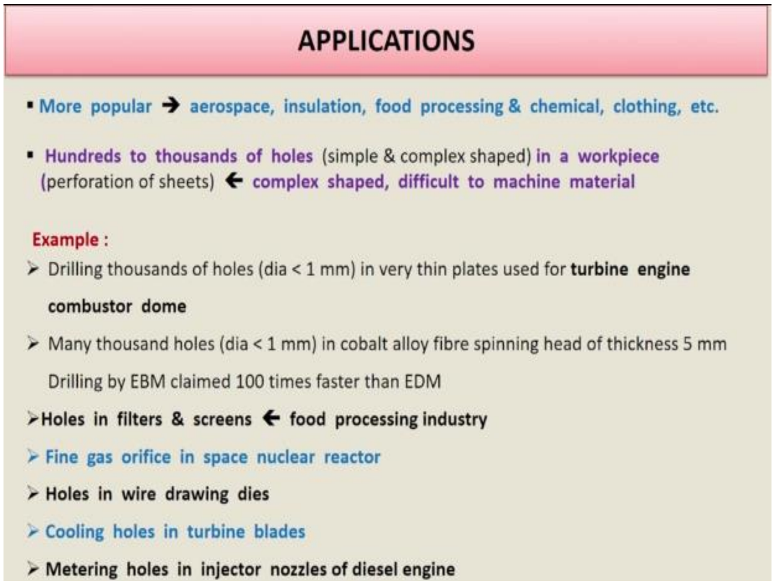

These are the applications of electron beam machining process. So it is most popular for aerospace, insulation, food processing and chemical, and clothing industries. Hundreds of hundreds to thousands of holes can be generated on the workpiece surface, in a simple and complex shape holes can be generated on the workpiece surface. Perforation of sheets on a complex shaped and difficult to machine material can be generated. Examples are drillings of thousands of holes diameter less than 1 mm in a thin plates used for turbine engine combustor dome.

Many thousands of holes less than, diameter less than 1 mm in cobalt alloy fibre spinning head of thickness 5 mm can be generated. Drilling by electron beam machining is claimed 100 times faster than EDM process. Holes and holes in filters and screens in food processing industry. Fine gas orifice in space nuclear reactor. Holes in wire drawing dies. Cooling holes in turbine blades. Metering holes injection nozzles of diesel engines can be made by electron beam machining process.

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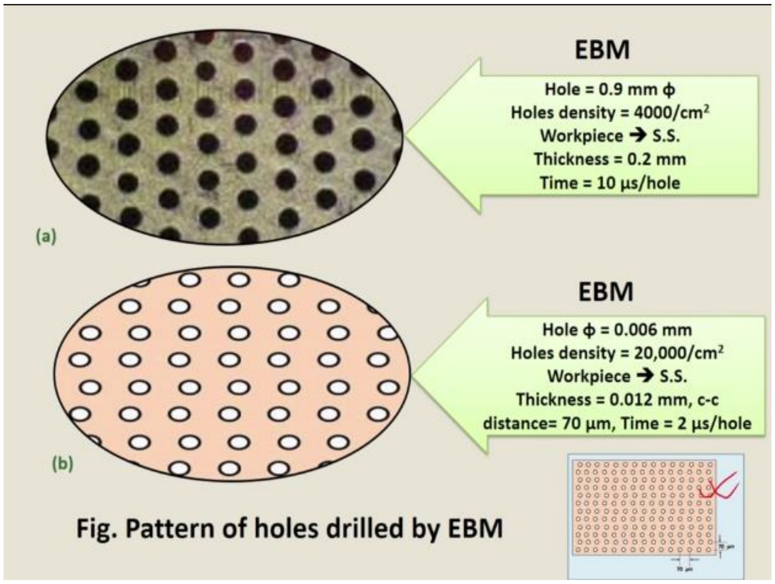

So you can see here there are so many holes are generated. All this hole diameter is circular hole diameter is 0.9 mm and hole density you can see here 4000 holes per cm square and workpiece material is stainless steel. Thickness of the workpiece material is 0.2 mm and time required per hole is 10 microseconds only. So here again you can see very small diameter holes around 6 micron is generated by this electron beam machining and here hole density is 20000 holes per cm square on a stainless steel workpiece of thickness 0.012 mm and distance is 70 micron and time is 2 microsecond per hole. So this kind of patterns or of holes are generated on workpiece surface by using this electron beam machining.

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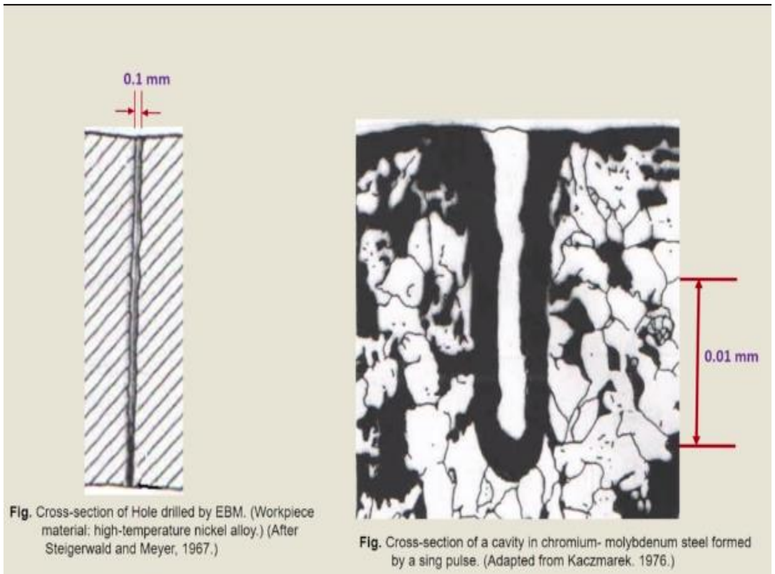

So here you can see a small holes, here you can see a small holes which is generated on the workpiece surface and here you can see the macro graph of the holes, cross section of the cavity in chromium, molybdenum steel formed by a single pulse.

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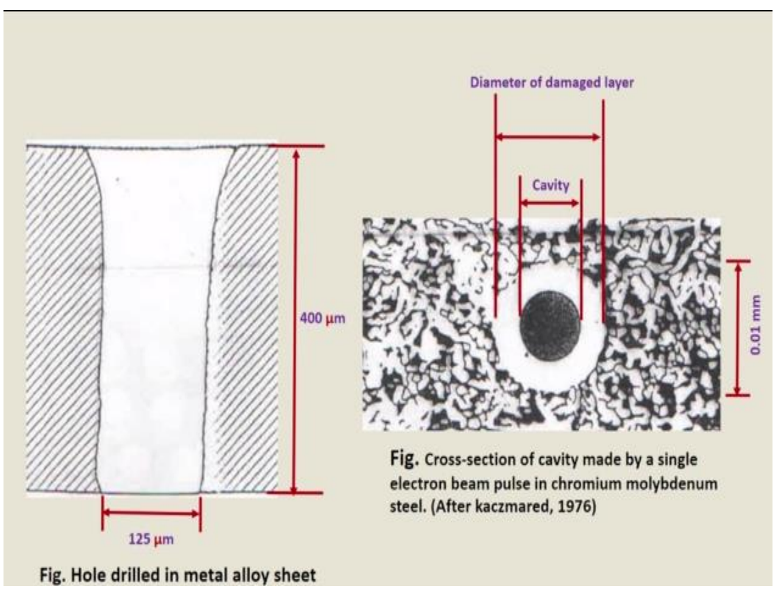

So here also you can see hole drilled in metal alloy sheet. So this kind of holes are generated by this process. So here also this cross section of the cavity made by a single electron beam pulse in chromium, molybdenum, steel which is generated by the electron beam machining process okay.

So with this I am going to stop this electron beam machining process. Thank you.