Metal Additive Manufacturing

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Lecture 11

Electron Beam Process

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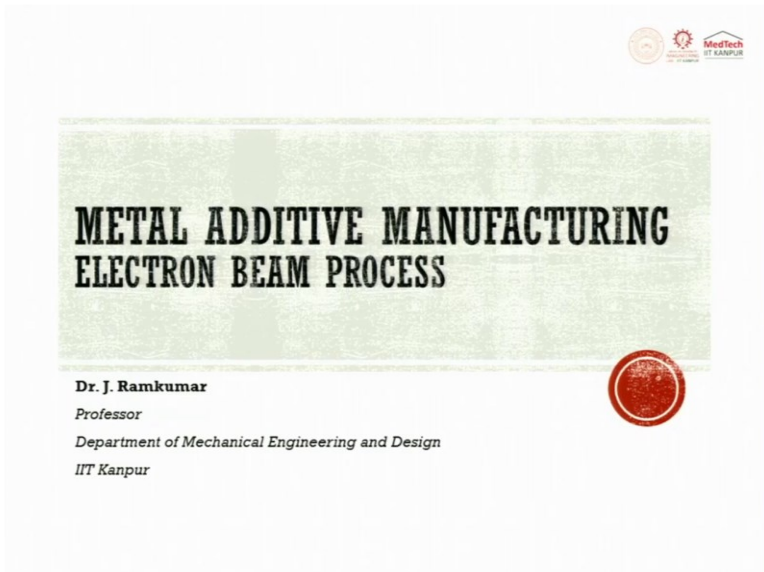

Welcome to the next lecture in the course Metal Additive Manufacturing on electron beam processing. In the last lecture we understood little bit of fundamentals about laser. In laser, we talk about 2 level 3 level 4 level. Second thing is we were trying to look into M^2 value, we were also trying to look at θ, the beam divergence.

So, these things are very much important because when we have to produce a high quality output these fundamentals are very much required because today world is moving very fast in developing different metal alloy powders. So, in that case process optimization is a very big challenge.

We will of course see a lecture exclusively on various process parameters using laser. In this lecture, we will try to cover about electron beam process. Laser beam process and electron beam process are the most prominent ones used in powder bed fusion technique.

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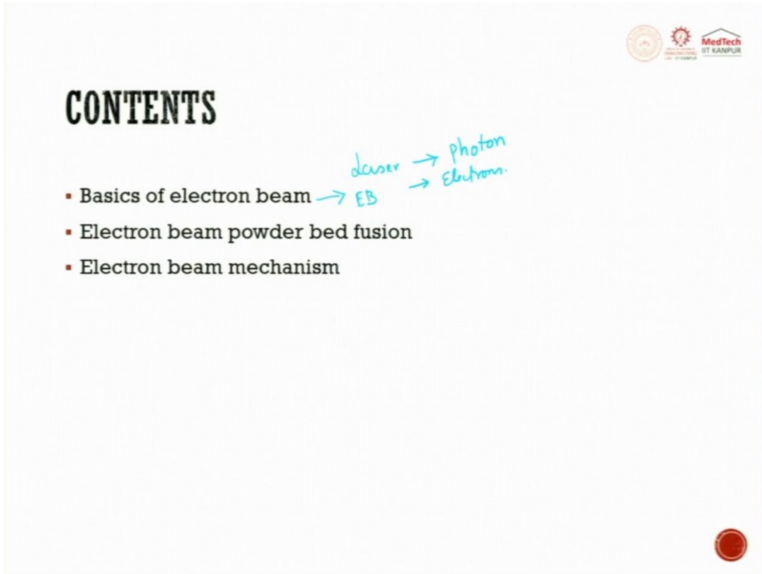

The content of this lecture is going to be basics of electron beam. When we discussed about laser, the basic small element is called as photons, photons are nothing but a packet of energy. When we talk about electron beam the basic small unit is electrons; a series of photons focused in a small point and you try to selectively sinter or melt was done in laser, in electron beam you replace that photon into electron.

So, here there will be a beam of electrons trying to hit at a powder where you can do electron beam sintering or you do electron beam melting. Predominantly, here we use only for electron beam melting.

We will see the basics of electron beam. Then we will see how is this electron beam powder bed fusion system exist. Then the last one is going to be electron, how is it generated, in mechanisms we will see electron beam mechanisms.

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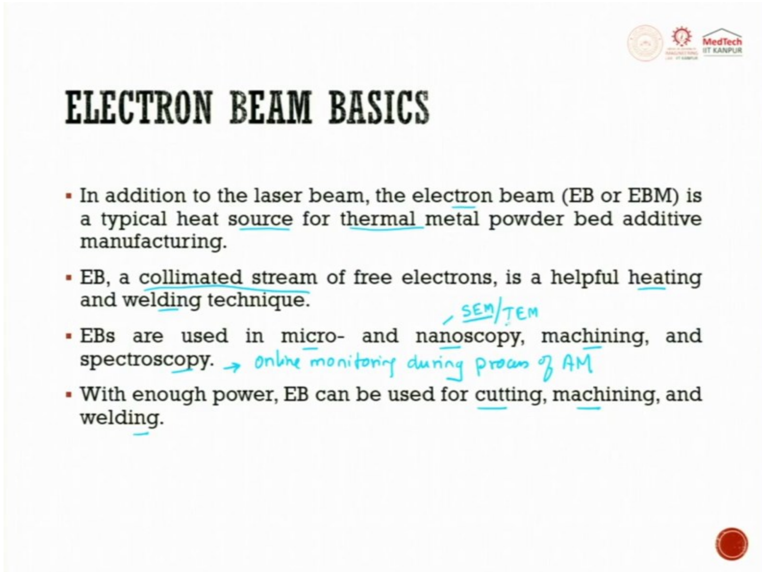

Like laser, electron beam is also a thermal source where in which this thermal source is used for melting and sintering to produce output doing it layer by layer approach. Electron beam is collimated, there we saw coherent. So, here we see collimated stream of free electrons are focused on a small spot for doing heating operation or doing welding operation.

The electron beams are nowadays used for microscopy and nanoscopy, it is used for machining, it is used for welding, and to a large extent it is also used for spectroscopic techniques today. These spectroscopic techniques are today used for online monitoring during the process of AM additive manufacturing.

The electron beam power is enough to cut machine and weld. The focus beam, if it is very small very high energy density comes, it can be used for cutting, machining and welding. Today, when we talk about processing micro and nanoscopy, you can think of using TESEM, you can also think of using TEM scanning electron microscopy or transmission electron microscopy, which falls in these two what I was talking about.

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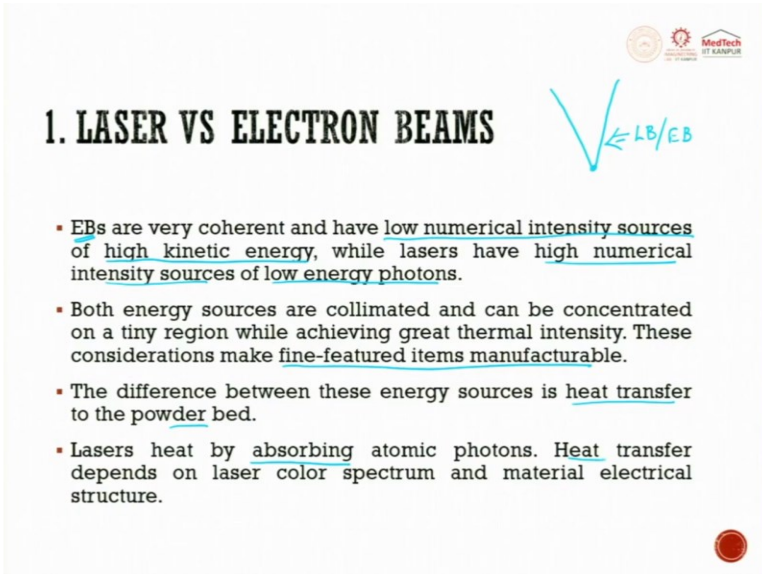

Let us try to compare laser and electron beam. Electron beam are very low numerical intensity sources of high kinetic energy, while lasers have high numerical intensity sources of low energy photons. High kinetic energy means lot of energy is there when it tries to hit at a powder. So, when it hits a powder immediately the temperature of the powder goes high and it starts melting. So, this is why electron beam is more preferred as compared to that of laser, but laser has its own advantage which you will be able to appreciate while going through this lecture.

Both energy sources are collimated and can be concentrated to a tiny region while achieving great thermal intensities. These considerations make fine feature items manufacturable when the laser beam or the electron beam hits at a small spot.

When it tries to hit at a small spot it can create fine features while doing AM. The difference between these energy sources is heat transfer to the powder bed. The laser heat by atomic photons absorbing. Heat transfer depends on laser color spectrum and material electrical structures. So, the heat transfer for laser generally depends on color and here it depends on material electrical structure.

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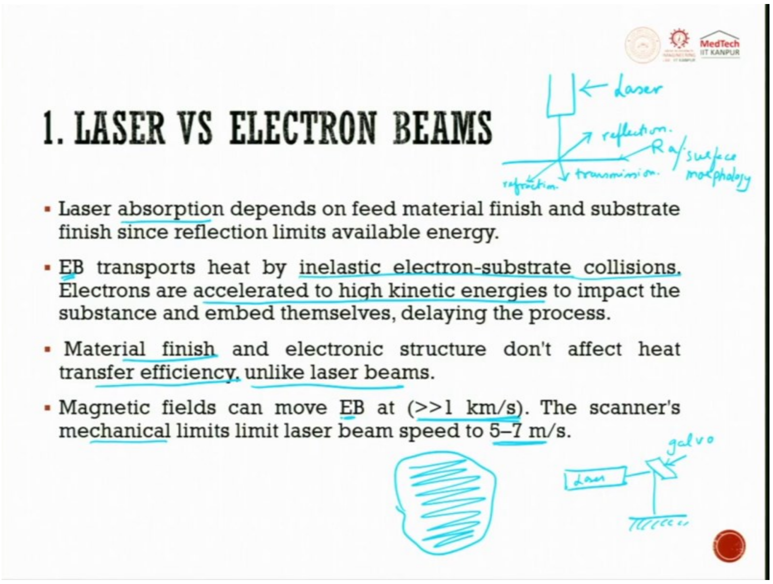

The laser absorption depends on feeding material finish and substrate finish since reflection limits available energy. What are we trying to say here is when a laser tries to hit at a surface, so you can try to have incident then you can try to have reflection. You can also have little bit of transmission and refraction, let us take it as transmission you can also have little bit of refraction.

But the reflection property or the absorption generally depends on the surface finish of the substrate or it tries to see what is the powder surface morphology. So, that does not reflected, gets into transmission or refraction, or it has to absorb. So, the electron transport heat by inelastic electron substrate collision.

So, it just hits the surface and it just penetrates the surface. The electrons are accelerated to high kinetic energies to impact the substance and embed themselves delaying the process. So, electron beam transports heat by inelastic electron substrate collision, the electron beam which comes tries to hit at the surface, and the electrons can be accelerated to higher kinetic energy by using electrical lenses or electromagnetic lenses or electric field lenses.

Whereas in laser, what we do is we try to use an optical phenomena to focus and try to increase the kinetic energy. Material finish and electronic structure does not affect the heat transfer. Unlike in laser, this is a very big advantage of electron beam. So, in electron beam, this is the biggest advantage as compared to that of laser.

So, it will have high kinetic energy and it will have very high heat transfer efficiency. So, that means to say the process efficiency goes high when we use electron beam as compared to that of laser. The magnetic field can move electron beam at around about 1 km/s. Look at the speed if you can do it at 1km/s. You can sweep very fast in creating the outer layer and the hatch patterns, you can create it very fast.

So, the machine building time is reduced to a large extent by using electron beam. The scanner mechanical limit limits the laser beam to 5-7 m/s. So, laser what happens is you will use laser then you will use a galvos, galvo system. This galvo system is predominantly mechanical base, it will be sweeping a light source to focus on the workpiece. So, this puts a limitation to 5-7m/s. So, this makes electron beam faster as compared to that of laser.

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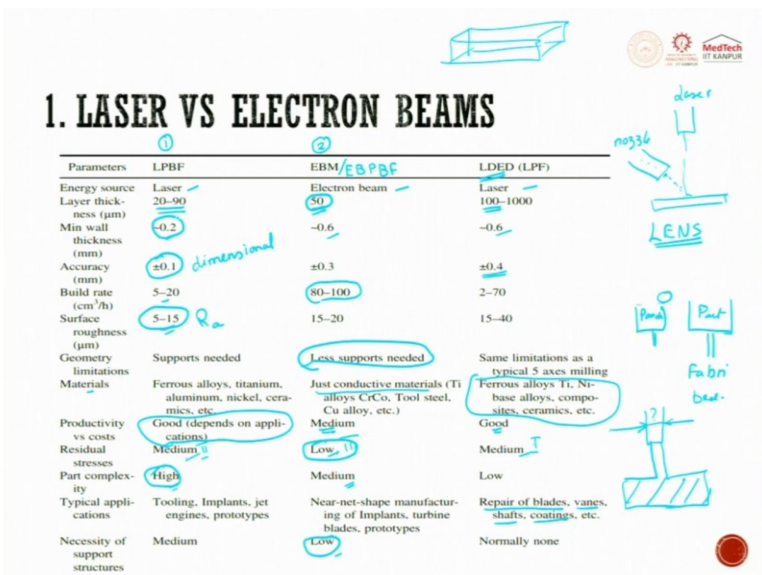

Parameters	LPBF	EBM/EBPBF	LDED (LPF)
Energy source	Laser	Electron beam	Laser
Layer thickness (μm)	20–90	50	100–1000
Min wall thickness (mm)	~0.2	~0.6	~0.6
Accuracy (mm)	±0.1	±0.3	±0.4
Build rate (cm^3/h)	5–20	80–100	2–70
Surface roughness (μm)	5–15	15–20	15–40
Geometry limitations	Supports needed	Less supports needed	Same limitations as a typical 5 axes milling
Materials	Ferrous alloys, titanium, aluminum, nickel, ceramics, etc.	Just conductive materials (Ti alloys CrCo, Tool steel, Cu alloy, etc.)	Ferrous alloys Ti, Ni-base alloys, composites, ceramics, etc.
Productivity vs costs	Good (depends on applications)	Medium	Good
Residual stresses	Medium	Low	Medium
Part complexity	High	Medium	Low
Typical applications	Tooling, Implants, jet engines, prototypes	Near-net-shape manufacturing of Implants, turbine blades, prototypes	Repair of blades, vanes, shafts, coatings, etc.
Necessity of support structures	Medium	Low	Normally none

Now let us try to compare three processes, one is laser assisted or laser used powder bed fusion method. The second thing is electron beam. I said machining here but you can try to do it as electron beam or electron beam powder bed fusion. And then, we have laser directed energy deposition.

Directed energy deposition means you will have a metal powder coming through a nozzle and then it tries to hit at the workpiece and then you have a laser which tries to hit at the workpiece. So, this is laser, this is nozzle and the nozzle will have metal powder. This metal powder flow rate is controlled and then when it tries to hit at a surface, the laser also tries to hit at the surface. It can be used for sintering or it can be used for melting.

So, laser directed energy deposition, the process called lens laser engineered net shaping predominantly uses the same technique. So, here energy source, the thermal source is going to be laser and here also it is going to be laser, and the next one here in between is going to be electron beam.

A stream of electrons, stream of photons and again here stream of photons. Let us look at layer thickness. The layer thickness is from the powder bed to the sample development bed, part manufacturing bed, this is powder bed and this is part manufacturing bed.

So, you will always have a recoater or a doctor's blade which tries to take powder from here and smear it on top of a surface. When it smears on top of a surface it always decides the layer thickness. The layer thickness in laser will be 20-90 μ whereas in electron beam it can go to 50 μ but in laser directed energy deposition it varies from 100-1000 μ.

So, here if you see this is an incoming powder. So, an incoming powder heating a surface on the workpiece, it does in one layer if you see it is like cladding when several cladded layers form together, it forms a three dimensional object. The minimum wall thickness is; what is the minimum? suppose you have a substrate like this, I have a substrate like this, this is called as the minimum wall thickness.

This minimum wall thickness for laser powder bed is 0.2, in electron beam it is 0.6, and in LDED it is also 0.6. Accuracies are 0.1 mm, that means to say it is talking about 100 μ accuracy. In laser powder bed fusion, here it is 300 μ, in electron beam melting it is 300 μ and in laser directed energy deposition it is 0.4 that is ± 400 μ.

If you are looking for a very good accuracy, we go for laser powder bed fusion; when you are looking for faster, then we go for electron beam. Now let us see the build rate. The build rate varies from 5-20 cm^3/hr, it is very slow cm^3/hr. So, it is approximately if you say take a volume of a 15 cm scale, its around about that.

So, we never build a solid object like this we will have so many other features coming in. Unless you want to do some mechanical property study, we always have multiple features in it.

So, this build rate whatever it is, might occupy a larger volume. So, 5-20 cm^3/hr and if you see electron beam it is 80-100 cm^3/hr. It is very fast, but the sacrificing thing is that you will have poor accuracies compared to laser bed and when the layer thickness is less so the accuracies might also be little higher.

So, if you have roughness, you see this fellow gives the best roughness. Laser powder bed fusion gives a roughness. So, roughness what we are talking about is the R_a, when we are trying to talk about accuracies it is a dimensional accuracy, here it is surface, here it is dimensional accuracies.

So, the geometric limitation here needs supports. So, here less support is needed, here the same limitation has a typical five axis milling machine. As far as laser directed energy deposition is concerned, in five axis machine you have all freedoms to do it. So, when we look into the material today there are so many exotic materials which are coming into application because the customer requirements have become stringent.

For example, they look for high strength, high toughness, high ductility material for may be aerospace automobile application. So, now we are thinking to develop or there is lot of development going on in the exotic material development. So, here the process parameter optimization is always difficult in each of these processes.

And again, generating these powders in a consistent manner itself is a huge challenge and there is lot of work going on. So, for metal atomization, people are working on nozzle spray. So, ferrous alloys, titanium alloys, nickel and ceramic are used as material here.

So, here in electron beam, the conducting materials alone can be used- titanium alloys, chromium, cobalt, tool steels, nickel alloys and copper alloys. When we talk about laser DED, here again you can use everything what we used here it is basically depending upon the material and the electron beam.

So, the productivity versus cost is very good. So, these two processes the costs or the initial costs are very low, but in electron beam the costs are very high.

So, the residual stresses which are introduced are medium here and low here. If you ask this will be the highest, next highest will be this, and the third highest will be this. What are residual stresses when we are trying to center or melt, the metal powder tries to shrink, when it tries to shrink it tries to introduce some of the tensile stresses, and in the top surface it will have tensile stresses and in the bottom surface it will have compressive stresses.

So, these two stresses in one layer also can happen, or between layers also it can happen, it can happen intra layer or inter layer and once it happens it tries to warp the material. So, these stresses has to be removed. So, what people do is after doing all this fabrication, they try to do a small heat treatment to anneal the sample such that they can get the best out of it.

So, part complexity can be very high in laser powder bed, in electron beam it is low. In directed energy because of the wall thickness, the undercut and all those things are very difficult. But in laser powder bed fusion it is good and in electron beam machining you have to focus the undercut and all is very difficult with respect to electron beam, so it is medium.

So, typical applications you can see tooling, implant, jet engines, prototyping here it is almost the same. Here it will be predominantly used for repair of blades, veins, shafts, coatings, etc. So, here we predominantly use it for refurbishing and re-coating. So, the necessity of the support of this it is medium, for this it is low and it is normally none for this.

So, now you see you are having several advantages, here for laser and several for electron. So, you have to hit a tradeoff while buying a machine for additive manufacturing.

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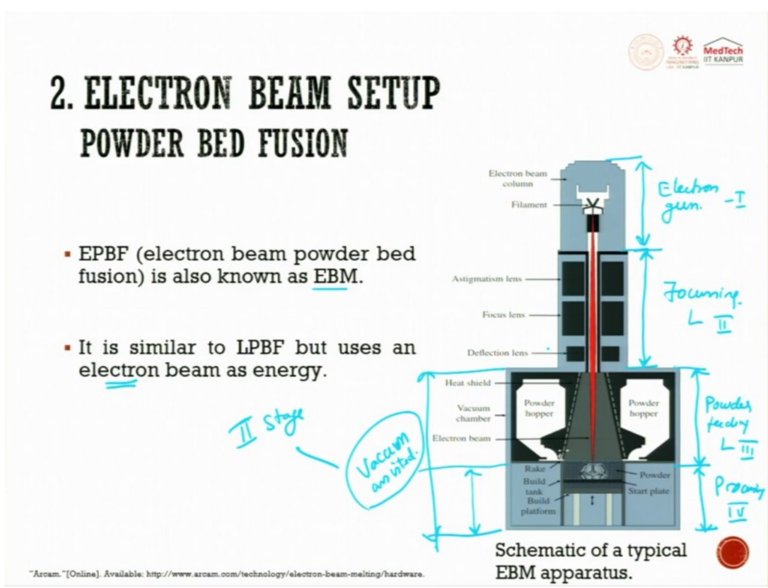

So, this is how a typical electron beam powder bed fusion setup looks like, you will have an electron here, if you see this is completely called electron gun. So, electron gun means it develops a stream of electrons and it pushes into the system, this portion of the system is predominantly for focusing.

This portion is predominantly for continuous focusing, it is predominantly used for powder feeding and the last one is called as for processing. It will have 4 stages. So, electron gun stage 1, then it will have focusing 2, then it will have powder feeding 3 and then it will have powder processing 4.

If you look at it very nicely, so this portion completely will be vacuum assisted, that means to say the entire process of feeding will be in vacuum along with machine building. Today, we are also trying to remove this portion and have only this portion as vacuum but it is a good idea to have the entire system.

So, why is electron beam very expensive? One of the reason is that, it is vacuum assisted. You have to create vacuum. Two stage vacuum will be there, one is called as the primary stage and the next one is called as the secondary stage, in the primary stage you try to move from atmospheric pressure to 10^{-3} torr or 10^{-4} , you go and from then on you go for a higher torr.

We also try to remove oil, small oil particles, vapors, and dust whatever is there. So, this makes it expensive and the next one is the electron gun. Predominantly, these electron guns cannot be switched on and switched off at regular intervals. Laser for example after the process is over, you can switch off the laser source but for electron gun, it is always difficult to switch it off and then switch it on.

In the sense, it is not a heavy job. But, I am saying it is not healthy for the system. So, once the electron gun is switched on, it keeps running continuously. So, this makes the system again expensive. So, this one is two stage vacuum electron gun and the next is a large area where vacuum has to be made.

So, all these things makes electron beam expensive. In Indian terms, if we talk about a very good descent electron beam machine for an area of around about 1 foot x 1 foot x 1 foot volume you are looking for, it is typically around about 10 crores, that is the cost of the machine. Whereas laser in the same spectrum you can get it somewhere between 60 lakhs to 80 lakhs.

And wherever I wanted to have a vacuum, I purge with gas and make sure the environment around the sintering portion or the melting portion is maintained neutral. So, that is easy gas cost and is not so expensive. So, that is what people are trying even now to buy laser beam compared to that of electron beam.

So, laser powder bed fusion is also known as laser beam machining. This was simplicity but if you try to use the same terminology in machining, electron beam machining is also there where cutting is the predominant phenomena. It is similar to that of laser powder bed fusion but uses an electron beam as energy. Moment, I use electron beam then I cannot use optical lenses I have to use this magnetic field lenses.

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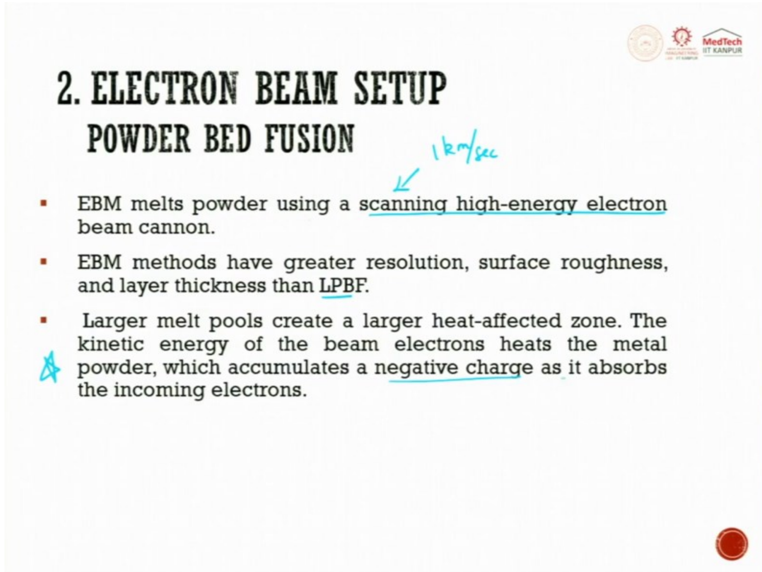

Electron beam machining melts powder using a scanning high energy electron beam cannon. The scanning where we were referring to about is 1 km/s, scanning. The electron beam machining method have greater resolution, surface roughness and layer thickness than LPBF which we compared.

The large melt pool creates a larger heat affected zone, the kinetic energy of the beam of electrons heats the metal powder which accumulates a negative charge as it absorbs the incoming electron, this point is very important. So, the electron beam heats the metal powder because of high kinetic energy, which accumulates a negative charge as it absorbs the incoming electrons.

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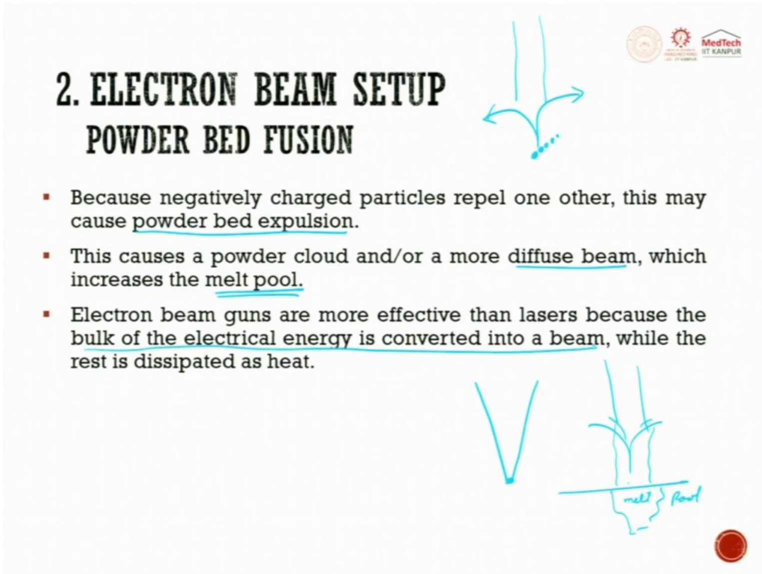

Because negatively charged particles repel each other this may cause powder bed expulsion. So, what do you mean by that so here there is lot of charged particles. So, each one try to repel so it tries to throw them out like this, it is like a flower pot during Diwali we celebrate. So, it is almost like that.

So, because negatively charged particles repel each other this may cause powder burn expulsion. This causes a powder cloud and or a more diffused beam. So, all these things when it go here when the new beam tries to hit, it tries to diffuse beam which increases the melt pool. So, normally what happens you are focusing here now. Now you will have lot of disturbance coming. So, now the electron whichever is there it is trying blurred and it comes down.

So, it tries to do so that is what we are trying? This causes a powder cloud and or a more diffuse beam which increases the melt pool. The electron beam gun is more effective than laser beam because the bulk of the electrical energy is converted into a beam while the rest is dissipated as heat. The bulk of the electrical energy is converted into beam. So, this makes the process efficient.

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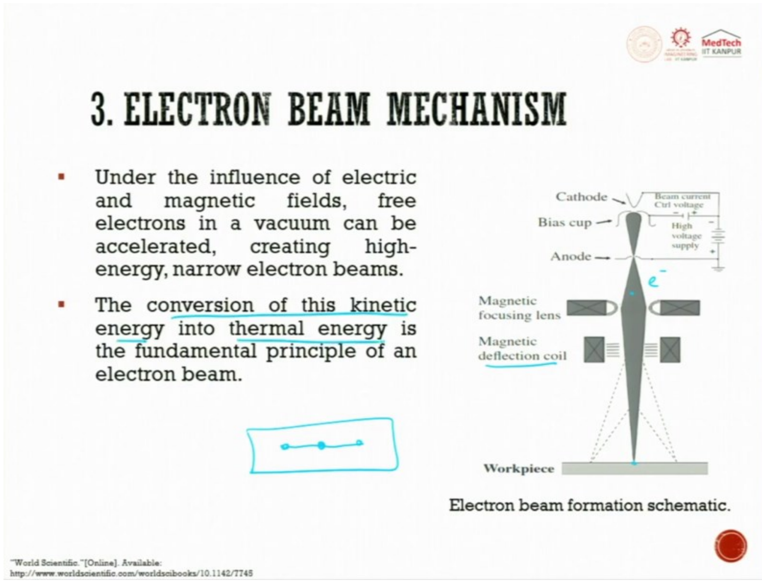

So, under the influence, now we will get. So, the electron gun is there that tries to create electrons. So, this jet of electrons enters into the focusing system. When they enter into the focusing system, you see magnetic focusing lenses there. Why? Because it is e which is there and this e can be focused or defocused by using magnetic field. The speed of e can be increased and decreased by the magnetic field.

So, the magnetic focusing lenses are used. Basically, you pass current through the coils and this creates a magnetic field. The e which goes inside the magnetic field gets now focused down to a small spot. So, you can see here this is focusing.

So, here it tries to go down and parallelly when you want to do a scanning operation of the beam, you have magnetic deflection coils which allows the beam to move left and right, so that you try to create a large area. If you look at the plain view, initially it was a spot here, now it is a spot here, now it is a spot here. So, it will try to move in this and then try to sinter powders.

Under the influence of electric and magnetic field the free electron in vacuum can be accelerated creating high energy narrow electron beam because of the magnetic field focus. Conversion of kinetic energy into thermal energy is the fundamental principle of electron beam.

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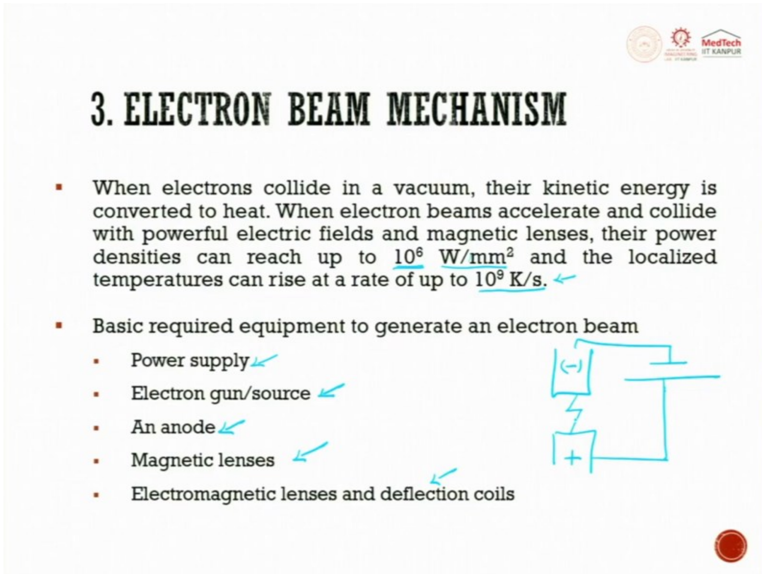

Now let us discuss about electron beam mechanisms. When electrons collide in a vacuum their kinetic energy is converted to heat. When electron beam accelerates and collides with powerful electric field and magnetic lenses, their power density can reach up to 10^6 W/mm^2.

And the localized temperature can raise at a rate up to 10^9 K/s. It is almost like a rocket speed, you hit it immediately the temperature goes high. Once the temperature goes high, then the powder melts, once it melts it diffuses heat into the next powder and the electron beam scan. So, now you see all these phenomenas go parallel. So, you get proper output or of good quality output by using electron beam.

So, the densities can go 10^6 W/mm^2 and the temperature rising rate will go to up to 10^9 K/s. So, this depends on the power and also this part. The basic required equipment to generate an electron beam is a power supply.

So, you need to have a power supply, how do you create electrons, you have two electrodes, you have negative, you have positive. Now between these two, you are trying to connect negative you are trying to connect it to a positive. So, when these two are at very high potential, you have dielectric in between so this dielectric whatever is there it breaks and then it tries to create a spark or an arc.

So, this process of avalanche of electrons getting created and getting focused to a smaller point is done by this electron beam. So, the avalanche of electrons come out because of the potential whatever you apply. So, the power supply is very important. So, power supply then is the electron gun I told you the source, then an anode, magnetic lenses, then electromagnetic lenses which is used. Electromagnetic lenses and deflection coil which is used for creating the electron beam is trying to hit at the workpiece.

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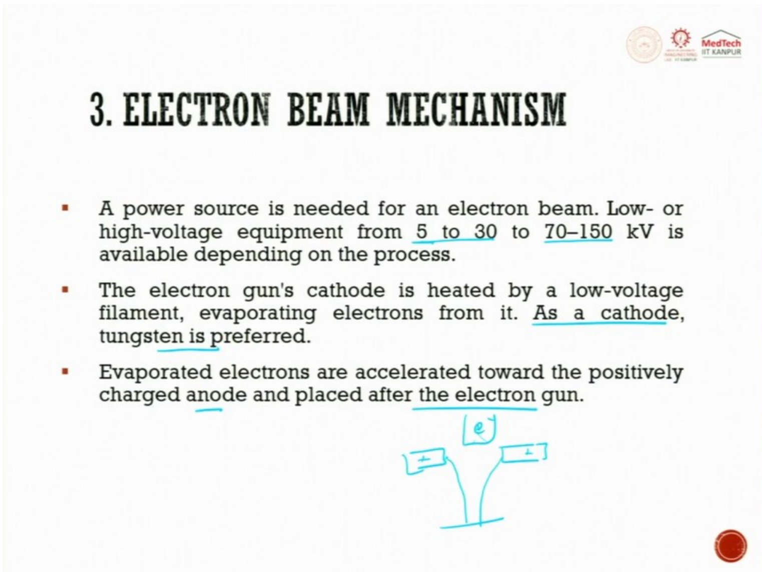

Power source is needed for an electron beam to be created. Low or high level voltage equipments from 5-30 or up to 70 -150 kV is applied between the electrodes. So, is up available depending upon the process very high power source you need. Next the electron guns cathode is heated, cathode is heated by a low voltage filament evaporating electrons from it. As a cathode, tungsten is preferred.

So, we use tungsten cathode for generating these electrons. The evaporated electrons are accelerated towards the positively charged anode and placed after the electron gun. So, the electrons whichever comes towards the positively charged anode are placed after the electron gun. This is the electron gun. So, what will happen? they will all be pulled and then go here from here what you do is you try to focus it down, it will not get attached here but it will try to go and then this will try to push, it will come down.

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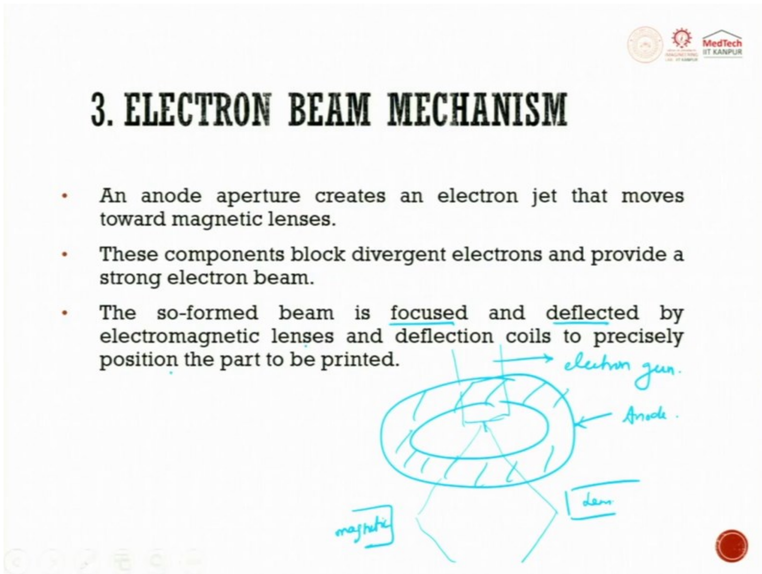

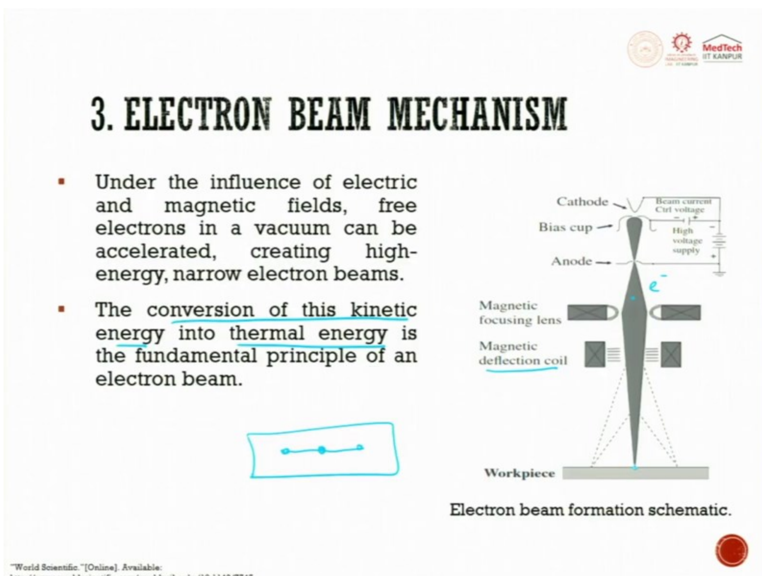

And anode aperture means something like a doughnut, and here you have your electron, this is your electron gun. An anode aperture creates an electron jet that moves towards the magnetic lens. These components block divergent electrons and provide a strong electron beam. So, it gets moved here then this is magnetic, then it all gets expanded. So, now what you do is you try to focus it down that is what we say here. The so formed beam is focused and deflected by the electromagnetic lens and deflection coil to precisely position the part to be printed.

So, this is what we are trying to talk about. So, these are deflection coils, these are focusing lens and this is what is the anode orifice you have. So, through this you have a thermal, this is tungsten, tungsten carbide electron is there, then you have a biased cup where you give the higher supply voltage.

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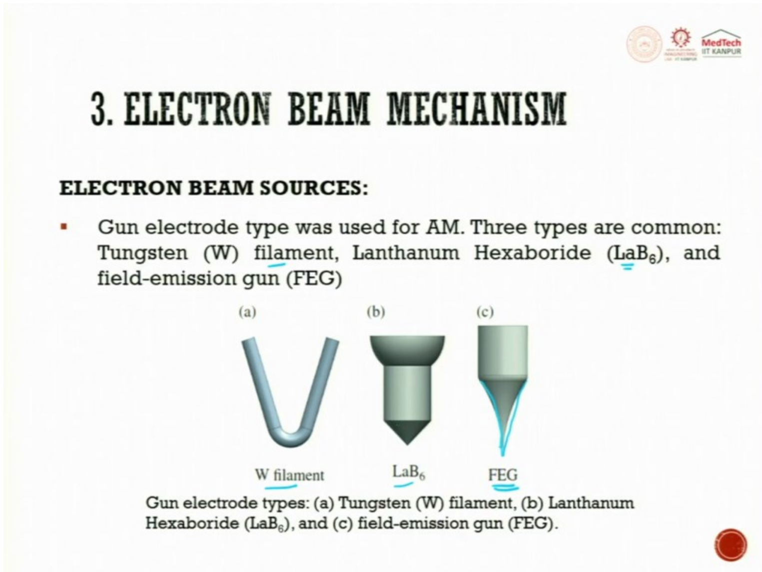

So, if you look at the electron beam source, there are various types of electron guns. The three most common ones are tungsten filament which is heated at a very high temperature so you apply a high potential. Next is lanthanum hexaboride which you have like this LaB_6, this is filament and this filament is nothing but a wire. Then the last one is field emission gun FEG field emission gun you have a Taylor's cone which is created in field emission. So, this will try to give you an idea how these guns work.

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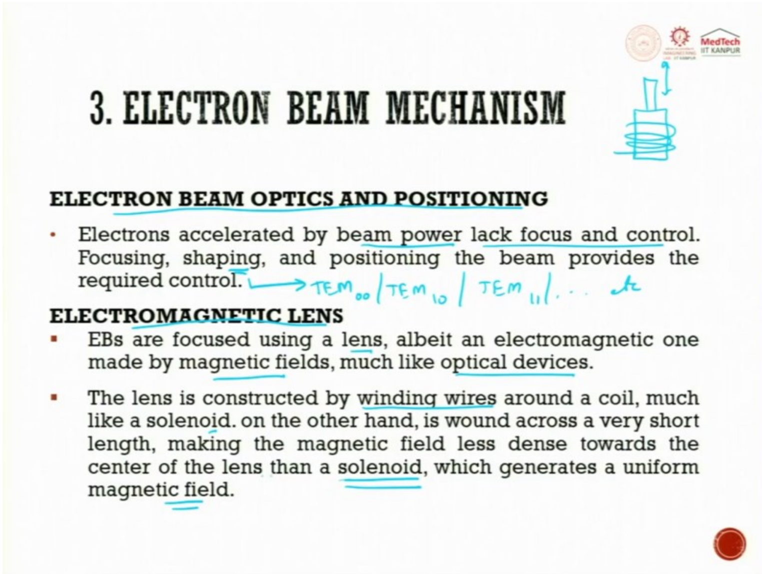

So, after electron is getting created from the gun, it moves. So, in electron beam, optics and positioning is the next important thing which you have to study. So, where in which we will try to study about stigmatization and then electromagnetic lens. The electrons accelerated by beam power lacks focus and control. So, the electron which gets accelerated, they just get accelerated by beam power but lacks focus.

So, this focus has to be done onto a spot.So for that we use the electromagnetic lenses for focusing, shaping and positioning. We studied in laser about TEM_{00} mode, TEM_{10} mode, TEM_{11} mode, etc. So, these things are shaping.

Electron beams are focused using lens albeit and electromagnetic ones made by magnetic field much like an optical device, like a lens you have in laser what we do is we have a lens and then on top of the lens we do a thermal barrier coating because the lens when it is hit by a laser beam, it will try to melt.

In order to avoid it, we do a thermal barrier coating. Transparent thermal barrier coating on lenses is a big challenge. But nowadays technology has come up very well and is matured. So, you have a lens which is coated with thermal barrier coating. In the same way here, we do not use optical devices, we use magnetic field devices where the lens is constructed by winding wire around a coil much like a solenoid.

So, what is a solenoid? This is a coil which is one and then you have a lever. So, this lever will go up and down by passing current to it. So, this lever will get stiffened by passing current. So, winding wire around a coil much like a solenoid on the other hand is bound across a very short length making the magnetic field less dense towards the center of the lens than a solenoid which generates uniform magnetic field. We are trying to take solenoid along with this because solenoid is one thing which you would have seen or you would have done experiments in your school days.

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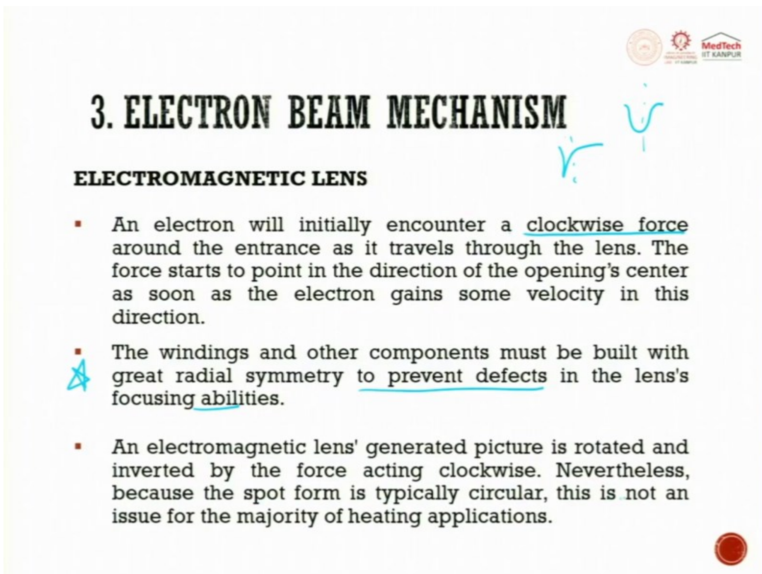

So, when we understand little bit more about electromagnetic lens, an electron will initially encounter a clockwise force you have to go back and relook into the right hand rule, left hand rule, Lawrence force all these things. So, when you go through those fundamentals you will understand this more in detail, an electron will initially encounter a clockwise force around the entrance as it travels through the lens.

So, it encounters a clockwise force. The force starts to point in the direction of the opening center as soon as the electron gains some velocity in the direction. So, assume that you have a box, inside the box you have a ball, you just keep rocking the ball inside it. So, after some point of time the ball gains velocity and then the ball will try to exit out from the box, it is almost the same.

The force starts to point in the direction of the opening center as soon as the electron gains some velocity in that direction. The windings and the other components must be built with great radial symmetry to prevent deflection in the lens focusing ability, this is a huge challenge to fabricate. Because we are talking about electron beam and the positioning, we are talking about in few hundred microns and it should be uniform, there should not be any disbalance in the spot focusing.

So, spot focusing is we always assume it is Gaussian distribution but it can also have skewness. So, if you have skewness then it becomes very difficult for you to get a good quality output. An electromagnetic lens generated picture is rotated and inverted by a force acting clockwise. Nevertheless, because the spot form is typically circular this is not an issue in the majority of the heating applications.

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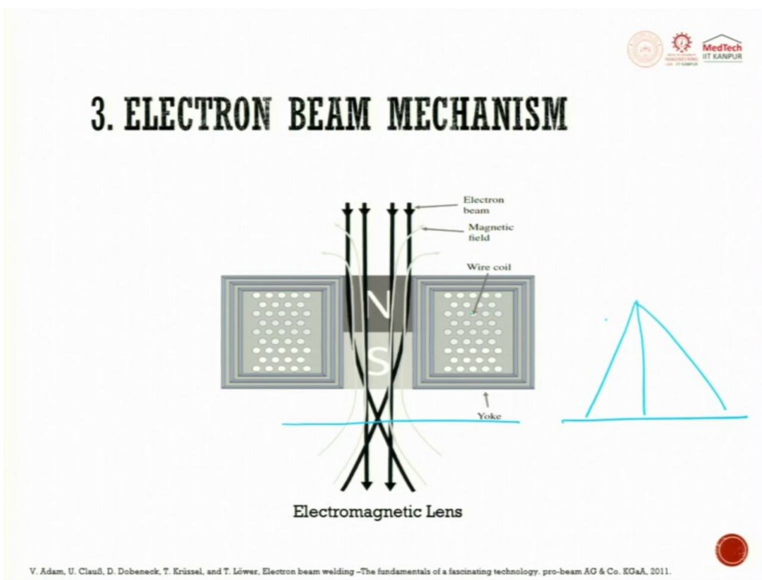

So, this is how it is, these are the electron beams which come, this is a north pole, this is a south pole you have wire coils which are wound. So, these coils will be going around. So, this is magnetic field, these white lines are magnetic field. You can see how this magnetic field tries to interact with the electron beam and try to focus the electron beam to a spot.

So, then at this point you try to do melting and you vary the positioning. So, that this can move either in a straight line or can move this way or this way to get a scanning, and then you start doing it. So, you can see these are all wire coils and these are all the yoke which is used to create electromagnetic field.

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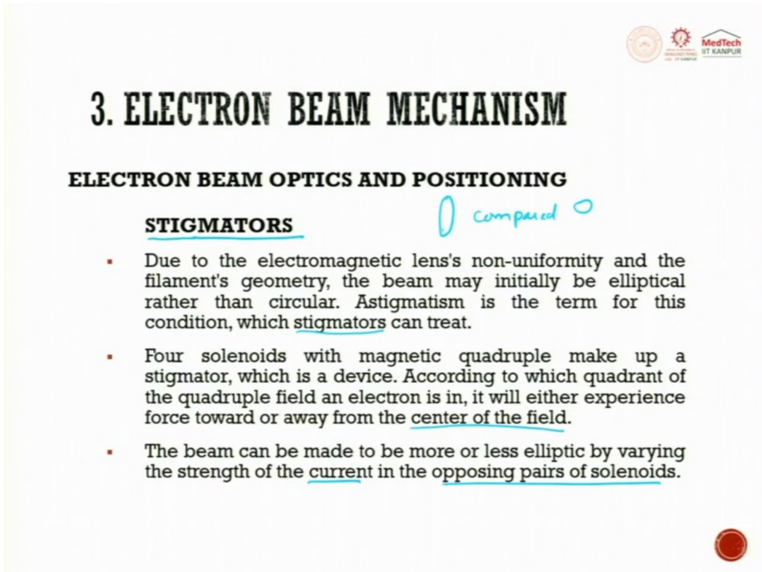

The next one is electron beam optics and positioning. So, we see here stigmators. Due to electromagnetic lens's non uniformity and filament's geometry, the beam may initially be elliptical rather than circular. So, whatever hits at the workpiece will be elliptical as compared to that of circular.

So, this phenomenon is called as astigmatism, which stigmators can treat. So, to convert this into this we use stigmators. Four solenoids with magnetic quadrupole makes up a stigmator which is a device according to which quadrant of the quadrupole field an electron is in, it will either experience force towards or away from the center of the field. The beam can be made more or less elliptic by varying the strength of the current in the opposing pair of solenoids. So, this whatever we are doing, you try to play with the current such that this astigmation or the elliptics can be converted into circular.

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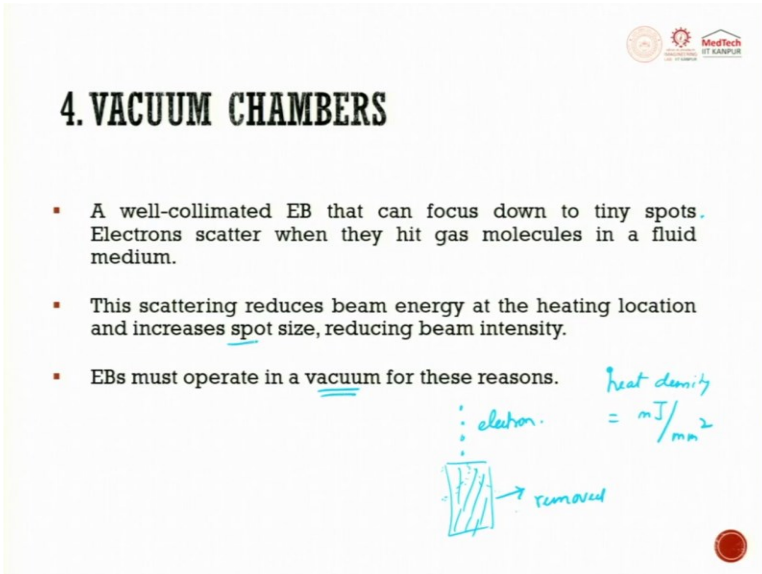

A well collimated electron beam can focus down to a tiny spot. Electrons scatter when they hit gas molecules in the fluid media. So, when an electron is coming it tries to hit and it tries to deflect out, assuming this is a fluid. So, this is what we are saying, this is electron.

A well collimated electron beam can focus down to a tiny spot. But if this electron passes through a gas fluid media it tries to get scattered. This scattering reduces the beam energy at the heat location and increases the spot diameter. So, when it tries to get deflected, what happens is the heat density mJ/mm^2 or whatever it is, this density decreases and electron beam must operate in vacuum for these reasons.

So, this fluid whatever is there has to be removed, the fluid here can be air, it can be liquid but predominantly we talk about air because why this vacuum will try to increase the energy and decrease the spot diameter.

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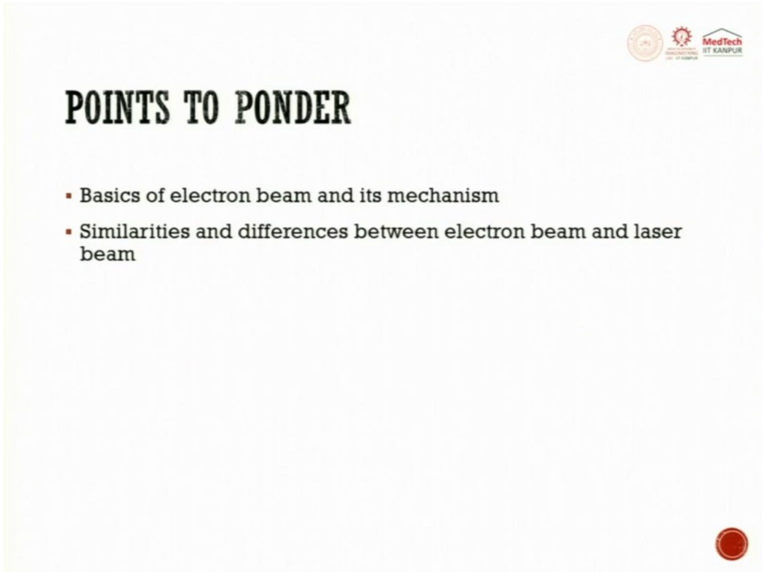

So, till now what we have gone through is all about electron beam processes. We have compared various process like laser powder bed fusion. We have compared electron beam powder bed fusion and laser directed energy deposition; we have compared this on various parameters. And then we saw why is electron beam machine expensive, it is expensive because of its existing subsystems.

The subsystems are you will have an electron gun, then you will have magnetic field lenses, then you will have powder feeding mechanism, the last one is going to be the vacuum assisted building space. So, all these things are subsystems of electron beam, powder bed fusion. We will see little more details on powder feeding in the next lecture.

Because if the powders are not fed properly, then you will not get a sound quality output. So, points to ponder at the end of the lecture is the basics of electron beam and its mechanism. Similarities and difference between electron beam and laser beam have been discussed.

So, assignment is: if you can google and find out few parts which are made out of electron beam and you write your inferences why is it not made by laser and we have chosen electron beam. If you can look out for answers that will be wonderful. And all these assignments are only for you to do self-learning, you need not submit the assignments. Thank you very much.