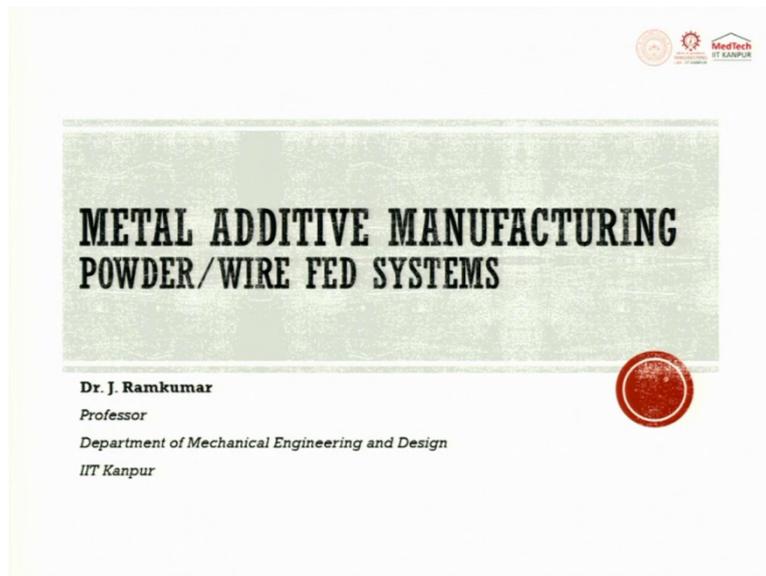


Metal Additive Manufacturing
Prof. Janakranjan Ramkumar
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Department of Mechanical Engineering and Design
Indian Institute of Technology, Kanpur
Lecture: 12
Powder/Wire Fed Systems

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Welcome to the next lecture, in the course Metal Additive Manufacturing. In this lecture, we will be seeing the electron beam process, the system in detail, in particular, the powder feeding mechanism, because this is a very important subsystem of electron beam machining or electron beam powder bed fusion technique. The metal powder when it is fed, the metal powder size will be approximately from 10 μ , it can go up to 60-70 μ , the biggest challenge of handling such powders will be the agglomeration.

What is agglomeration? agglomeration means the surface area is large, the volume is small, and in the surface area you are accumulating lot of charges and if these charges are positive-negative they try to stick with each other, assuming a condition that oil or water is not present between the powders. So, we have to find out ways and means how do you dispense these metal powders without getting agglomerated.

Why is agglomeration important? Because this agglomeration in turn will try to dictate the minimum wall thickness, the surface area whatever you are generating and also defects which are produced in this metal additive manufacturing. So, we will be looking at it in detail about powder feeding mechanism.

At last, we will be looking at wire feeding. We cover it very quickly because the wire feeding mechanism is almost very well dealt in all of the welding courses or this is already well known when we are trying to do material extrusion method in polymers and ceramics. So, we will have a very small glimpse as far as wire fed systems are concerned.

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The slide features a title 'CONTENTS' in bold black letters. Below it is a bulleted list of topics: Powder feeders and their classification, Powder Delivery Nozzles, Powder bed delivery and spreading system, Wire Fed Systems, Positioning Devices, and Print-heads. To the right of the list is a hand-drawn diagram in blue ink. The diagram shows a vertical flow: 'Electron source' at the top, followed by 'beam delivery', then 'Powder delivery', and finally 'Process'. A box around 'Powder delivery' and 'Process' is labeled 'Sintering' and 'melting' with arrows pointing to 'metal Powders' at the bottom. Logos for IIT Kanpur and MedTech are in the top right corner.

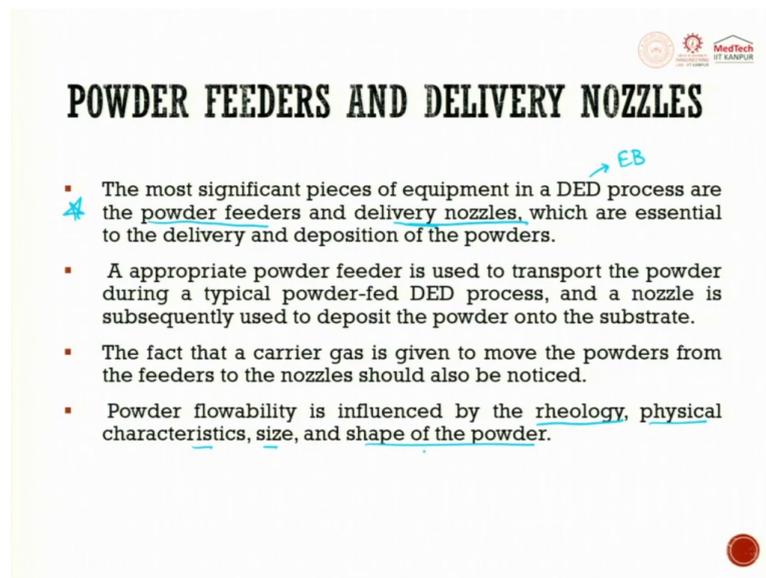
The content of this lecture is going to be powder feeders and their classifications. Next is powder delivery nozzles, that is a big challenge, if you can reduce the nozzle diameter further down, for example to diameter of $100\ \mu$, $50\ \mu$, $20\ \mu$, then the dispensing of the powder will be controlled in a very big manner. So, powder delivery nozzle, if it is only liquid, it is straight forward here, you have air as well as powder, so powder delivery nozzle will be the second one.

The third one is going to be powder bed delivery and spreading system. Last, we will try to see wire fed system, then its positioning, and finally print-head in this process. So, before going to detail, let us just have a small recap of all the four subsystems of electron beam powder bed fusion method. This is the electron source, this will be the beam delivery system, this is powder delivery system, and here is the process which is happening, the process are going to be either sintering or melting of metal powders.

These are all quiet common subsystems for electron beam laser bed fusion system. So, what we see in electron beam is also common for directed energy deposition method. So, the powder feeding mechanism and the nozzle which is attached to the powder feeding is almost

common for these two processes. So, from now on we will try to look at powder delivery system and nozzle which is attached for directed energy deposition method, which is similar to that of electron beam method.

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POWDER FEEDERS AND DELIVERY NOZZLES

- ★ The most significant pieces of equipment in a DED process are the powder feeders and delivery nozzles, which are essential to the delivery and deposition of the powders. → EB
- A appropriate powder feeder is used to transport the powder during a typical powder-fed DED process, and a nozzle is subsequently used to deposit the powder onto the substrate.
- The fact that a carrier gas is given to move the powders from the feeders to the nozzles should also be noticed.
- Powder flowability is influenced by the rheology, physical characteristics, size, and shape of the powder.

The most significant piece of equipment in a directed energy deposition process are the powder feeder, it is here as well as in electron beam, okay, powder feeder and delivery nozzle these two are very key terms, powder feeding, and delivery nozzle, which are essential to the delivery and deposition of the powder.

Appropriate powder feeder is used to transport the powder during a typical powder fed directed energy deposition process and a nozzle is subsequently used to deposit the powder onto the substrate, whatever is dealt here maybe up or down with some modifications we use it for electron beam. The fact that a carrier gas is given to move the powders from the feeder to the nozzle should also be noticed.

The powder flow ability is influenced by the rheology, physical characteristics, size, shape of the powder, rheology means the way it is flowing is called as rheology, right.

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The slide features the title "POWDER FEEDERS AND DELIVERY NOZZLES" in bold black text. In the top right corner, there are logos for "MedTech" and "KIIT". Handwritten blue notes include "mm³/min. or mm³/litre or gm/min." with an arrow pointing to the first bullet point, and "DED + EB → PBF" below the second bullet point. The slide contains two bullet points: "Controlling the powder feed rate, which is based on the flow-ability of the used powders, is crucial for maintaining a stable powder stream." and "In order to precisely control the feed rate and produce a continuous and homogeneous powder stream during AM operations, various types of powder feeders have been developed." A small red circular logo is in the bottom right corner.

Controlling the powder feed rate, so, we talk about mm^3/min . So, mm^3/min is what is the volume of material dispersed in a minute. So, we can try to talk in terms of mm^3/l air or whatever it is, right. Generally, we also call it in g/min , so all the three terminologies are used, whenever we talk about powder, we use this g/min .

So, controlling the powder feed rate is based on the flow ability of the used powder and is crucial for maintaining a stable powder stream. When the powder is flowing you cannot have a mute zone, for example when the powder is fed, it is not only going to be the powder, powder and also gas will be mixed, but it will be used in a very small extent. So, this will try to focus and hit at a spot and where you have to make sure the stream of flow constant.

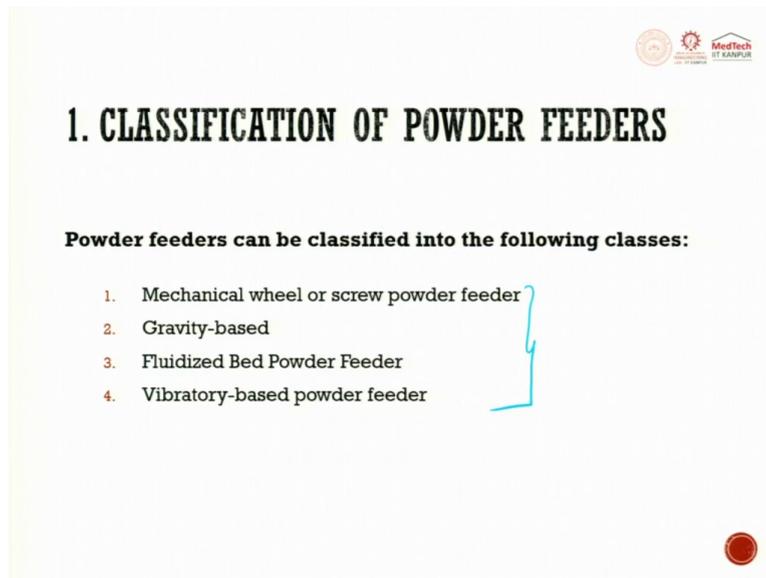
In order to precisely control the feed rate, and produce a continuous and homogeneous powder stream during AM operations, various types of powder feeders are deployed. So, this is used for DED and it can also be used for electron beam method. Sometimes, electron beam method also uses powder bed fusion and in powder bed fusion you have a recoater which smears the powder from the powder container. Predominantly, in DED, the powder feeders play a very important role.

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1. CLASSIFICATION OF POWDER FEEDERS

Powder feeders can be classified into the following classes:

1. Mechanical wheel or screw powder feeder
2. Gravity-based
3. Fluidized Bed Powder Feeder
4. Vibratory-based powder feeder



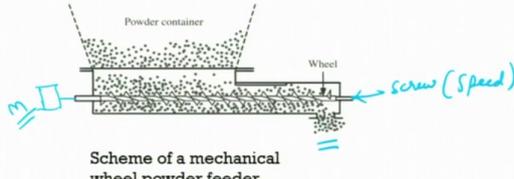
When we talk about powder feeder, they are classified into four, the first one is going to be mechanical wheel or screw powder feeder, the next one is going to be gravity based, the third one is going to be fluidized bed powder feeder, the last one is going to be vibratory based powder feeder. There are many more, but these four are the most commonly used powder feeders in metal additive manufacturing.

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1. CLASSIFICATION OF POWDER FEEDERS

1. MECHANICAL WHEEL OR SCREW POWDER FEEDER

- The mechanical wheel powder feeders consist of a container with a blade or screw operated at one end varying flow rates can be attained depending on the blade's arrangement.



Scheme of a mechanical wheel powder feeder

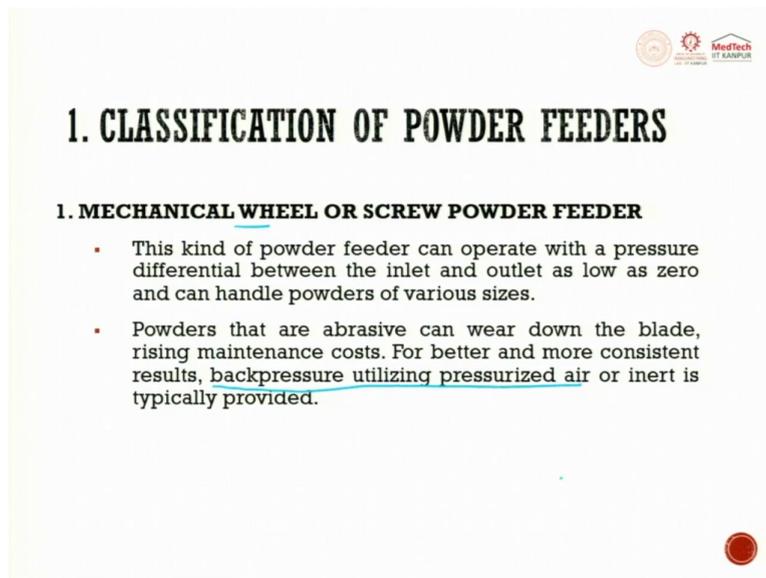
E. Toyserkani, A. Khajepour, and S. Corbin, Laser cladding, 1st edition, CRC Press, 2004. <https://doi.org/10.1201/9781420039177>

What is a mechanical wheel or a screw powder feeder? Here a mechanical wheel powder feeder consists of a container, this is a container with a blade or a screw operating at one end.

This is the screw. Screw operated at one end varying flow rate, so the screw speed is changed, so the flow rates are changed.

The varying flow rates can be attained depending upon the blade arrangement. So, you can have this as a container, this container comes down and in this you will have a screw which keeps rotating, this will be attached to a motor. So, once it is attached to a motor it rotates, so the flow rate gets changed, it is an exaggerated way, but generally it will be very small.

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The slide is titled "1. CLASSIFICATION OF POWDER FEEDERS" and is part of a presentation from IIT Kanpur, MedTech. It details the "1. MECHANICAL WHEEL OR SCREW POWDER FEEDER". The text explains that this feeder can operate with a pressure differential as low as zero and handle various powder sizes. It also notes that abrasive powders can wear down the blade, increasing maintenance costs, and that backpressure utilizing pressurized air or inert gas is typically provided for better results.

1. CLASSIFICATION OF POWDER FEEDERS

1. MECHANICAL WHEEL OR SCREW POWDER FEEDER

- This kind of powder feeder can operate with a pressure differential between the inlet and outlet as low as zero and can handle powders of various sizes.
- Powders that are abrasive can wear down the blade, rising maintenance costs. For better and more consistent results, backpressure utilizing pressurized air or inert is typically provided.

This kind of powder feeder can operate with a pressure differential between the inlet and the outlet as low as zero and can handle powders of various size. So, that is the advantage of mechanical wheel or screw powder feeder, the powders that are abrasive can wear down the blade, rising maintenance cost. For better and more consistent result, back pressure is utilized, pressurized air or inert gas, which will be mixed and will be sent along with the powder.

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1. CLASSIFICATION OF POWDER FEEDERS

2. GRAVITY-BASED POWDER FEEDER

- Gravity causes powder particles with the right flowability to pass through an orifice in gravity feeders. By adjusting the orifice area, one can manage how much powder enters the delivery nozzle.
- Furthermore, external metering components can be added to achieve a high precision feed rate.
- For instance, by adjusting the speed of a rotating disc with holes, a precise volumetric feed rate has been achieved.

Based on this idea, other components of a similar nature have been created, replacing the rotating disc with a metering wheel or a lobe gear.

Feeder nozzle
Plate 1
Plate 2

The next important powder feeding mechanism is based on gravity. Using gravity for the advantage is one of the thumb rules, when we try to transport material. So, lot of people always look for using gravity as their advantage. If you look into books which talk about design for assembly, disassembly, they will always say use gravity for your advantage.

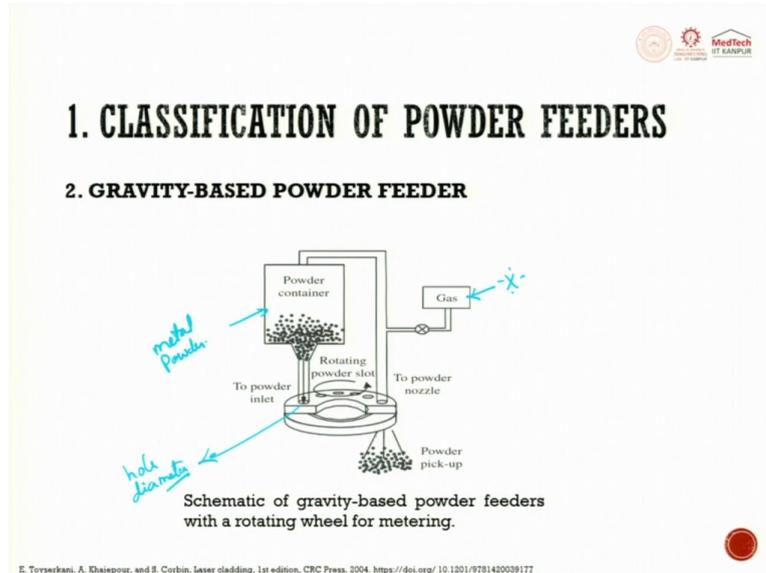
So, gravity-based powder feeder, gravity causes powder particles with the right flow ability to pass through an orifice in gravity feeder. By adjusting the orifice area one can manage how much powder enters the delivery nozzle. So, what does it mean you have powder feeder, this will lead to a nozzle. So, what exits from the powder feeder and gets into the nozzle, you can try to dictate it by changing the orifice.

Furthermore, external metering components can also be added to achieve the high precision feed rate. For instance, by adjusting the speed of rotating disc with hole a precise volumetric feed rate can be achieved. For example, if you have a two-plate system, so this is one plate, where there are holes, you can have another plate where there are holes. Now, these are plates, plate 1, plate 2, so these plates will be stacked one above each other, this is plate 1, this is plate 2.

So, now what will happen, you try to rotate it in such a fashion such that you can have a precise volumetric feed rate. Based on the idea other components of a similar nature, so here what happens, this will rotate, you can keep this as stationary, okay. So, every time you can try to control the whole alignment and then you try to get, based on this idea other

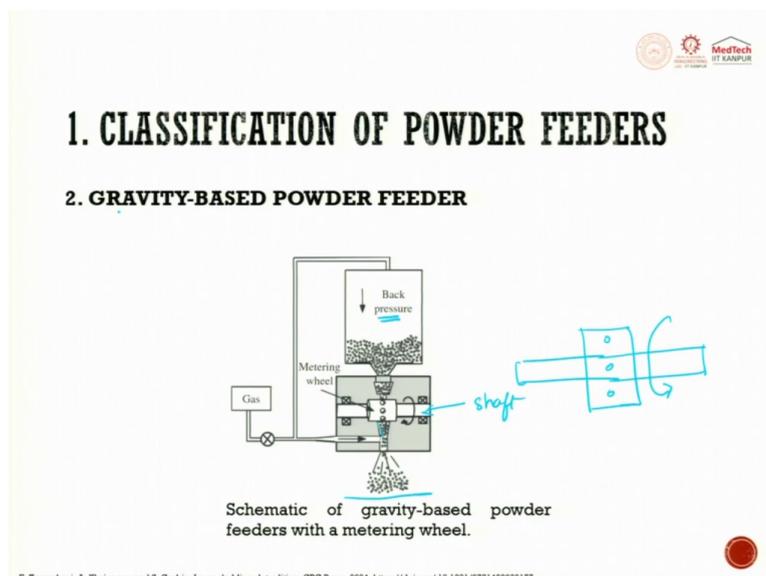
components of a similar nature have been created, replacing the rotating disc with a metering wheel or a lobe gear.

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So, this is how it looks like. So, you will have gas which comes inside, then you have a hopper where you have the metal powder. So, now this has an orifice, this orifice is connected through a nozzle to a plate on the top. So, this plate rotates, okay and the other end you will have powder which is getting ejected. So, the gas pressure is also important, then here you will have the hole diameter, the hole diameter is also important, because that dictates the amount or the volume of the metal powder.

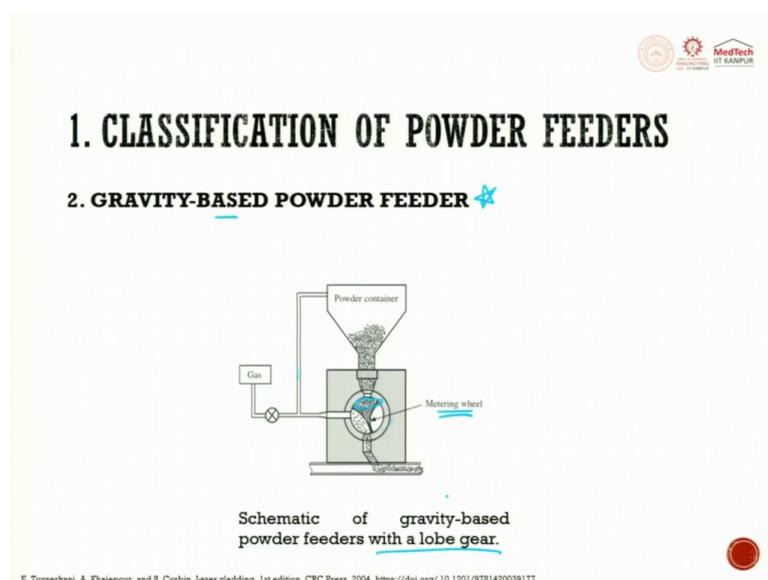
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Use it like this or you can think of using it like this. So, this is another schematic diagram of a gravity-based powder feeder with a metering wheel. So, you can have something like this. So, you have the air, gas which goes, generally, we try to use inert gas, it goes inside a hopper, where they create a back pressure. So, these abrasives or the metal powders flows down and here what happens is it is placed in a shaft, where this shaft is attached to a roller and this will try to rotate.

So, you have bearings, shafts, and this will rotate, and once it rotates, the other end you will have an orifice, so this orifice tries to push the abrasive down. So, you can see here this gas is used for back pressure, this gas is also used for making sure that the metal powders whatever it flows try to gets spread on top of a powder bed, okay. So, this powder bed or on a substrate where you want to go, this is the second type of gravity-based powder feeder used in directed energy deposition method.

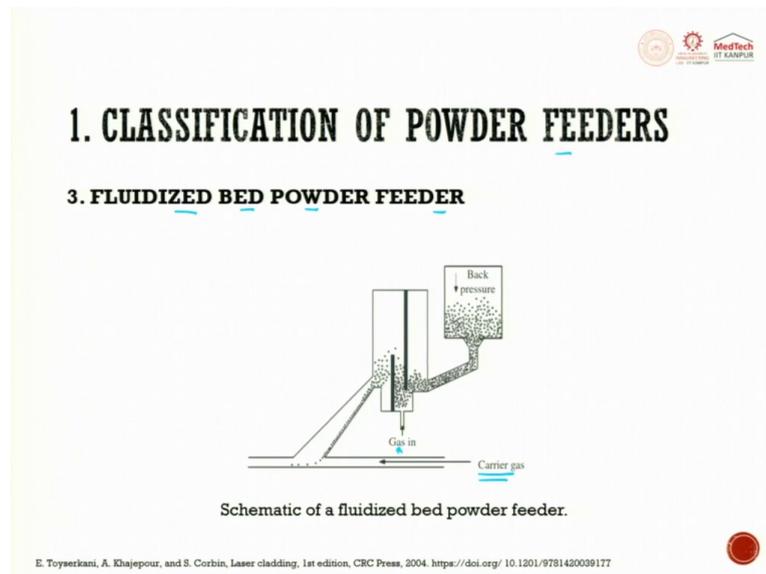
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The third one which is gravity based, is such thing which comes free of cost. So, you do not have to pull or push something, it falls of its own. So, the other way around is we have a gravity feeder with a lobed gear. So, with a lobe gear, you will have powder feeder. This powder feeder is the container and here you attach it with gas and then you also connect it directly with the nozzle exit, wherever it is.

So, here what happens, the abrasives or the metal powder gets accumulated and this is rotated, once it is rotated, it comes to an exit orifice, it tries to exit out and the metal powder is fed continuously. So, this is metering wheel which tries to control the flow.

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The next classification of powder bed feeding system is going to be fluidized bed powder feeder. So, here what happens we will try to have a back pressure which is created and then this passes through a hopper where there are two stoppers, this goes, the metal powder flows like this and you will have a gas injecting point, this will try to inject gas and you try to allow the metal powders to pass through this topping and enter through the hopper.

This through the hopper or through the orifice, it comes and deposits on to a plate or a substrate and you can see carrier gas is also fed here, so that the powder can move along with the carrier gas. So, fluidized bed tries to give a more controlled fashion of powder feeding, and here all the humidity and other things are removed nicely because of the involvement of fluid, fluid is nothing but air.

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The slide features a title '1. CLASSIFICATION OF POWDER FEEDERS' in bold black text. Below it, '3. FLUIDIZED BED POWDER FEEDER' is written in bold black text with a blue handwritten arrow and the words 'much used' next to it. Three bullet points follow, each starting with a red square. The first bullet point discusses the patent and the term 'fluidized bed powder feeder'. The second bullet point lists benefits, including the absence of mechanical components and lower costs. The third bullet point mentions high coating quality. Logos for IIT Kanpur and MedTech are in the top right, and a red circular logo is in the bottom right.

Based on the patent discovered from the fluidic principle, the fluidized bed powder feeder was created. Fluidized bed powder is exhaustively used for coating of tablets, for heat exchange or for removing humidity all these things. The benefit of this powder feeder is that it does not use any mechanical component to deliver the powder which lowers the cost of upkeeping and part replacement.

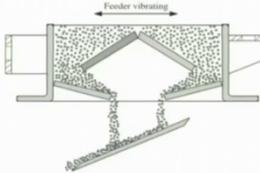
So, if there is a wear and tear in the powder feeder, then the amount of material which is getting dispensed will not be controlled, so your quality of the output is a big difficult task here. So, fluidized bed powder feeder are very much used, because here it is predominantly air that tries to drive it a very high coating quality is guaranteed by the uniform and continuous powder stream.

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1. CLASSIFICATION OF POWDER FEEDERS

4. VIBRATORY-BASED POWDER FEEDER

- It consists of a tray that oscillates at 50 or 60 Hz. The volume flow of the powder can be infinitely adjusted to ensure a steady-state powder flow as it moves from the hopper to the vibrating tray.



Schematic of a vibratory-based powder feeder.

E. Toyserkani, A. Khajepour, and S. Corbin, Laser cladding, 1st edition, CRC Press, 2004. <https://doi.org/10.1201/9781420039177>

A specific volume of gas is delivered to a closed hopper that contains the powder as a basic operating principle. So, if you go back this is what we are talking about a gas, which is injected where the powder is flowing. A filter at the bottom of the closed hopper diffuses the gas through the powder fluidized it. A pickup tube and a carrier gas are mounted on the top of the units to deliver the fluidized powder under a shed and to feed hose respectively.

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1. CLASSIFICATION OF POWDER FEEDERS

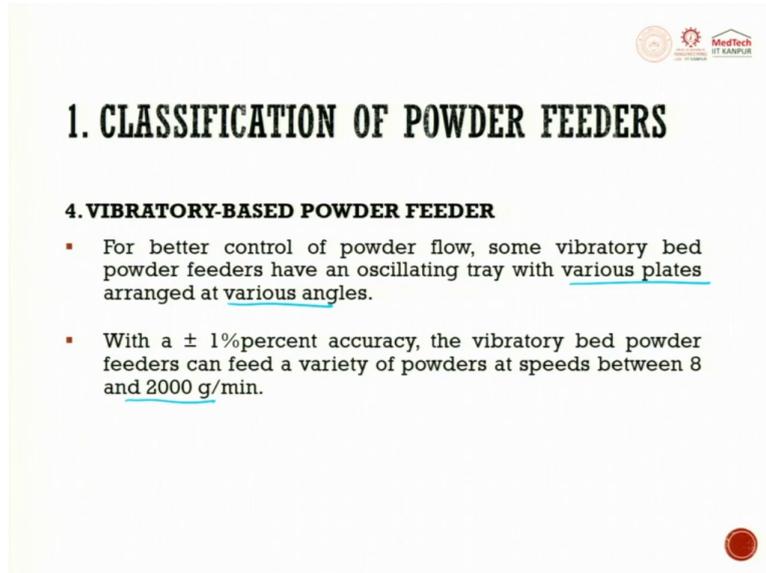
4. VIBRATORY-BASED POWDER FEEDER

- For better control of powder flow, some vibratory bed powder feeders have an oscillating tray with various plates arranged at various angles.
- With a $\pm 1\%$ accuracy, the vibratory bed powder feeders can feed a variety of powders at speeds between 8 and 2000 g/min.

So, this is the, all about fluidized bed-based powder feeder. The last one which we will see is vibratory based powder feeder. It consists of a tray that oscillates at 50-60, so this is indefinitely adjusted to ensure a steady state powder flow as it moves from the hopper to the

vibrating tray. So, here it is vibrated, these are all constants, so from here it gets dispensed and then falls on a tray, from a tray it gets into the plate wherever it is.

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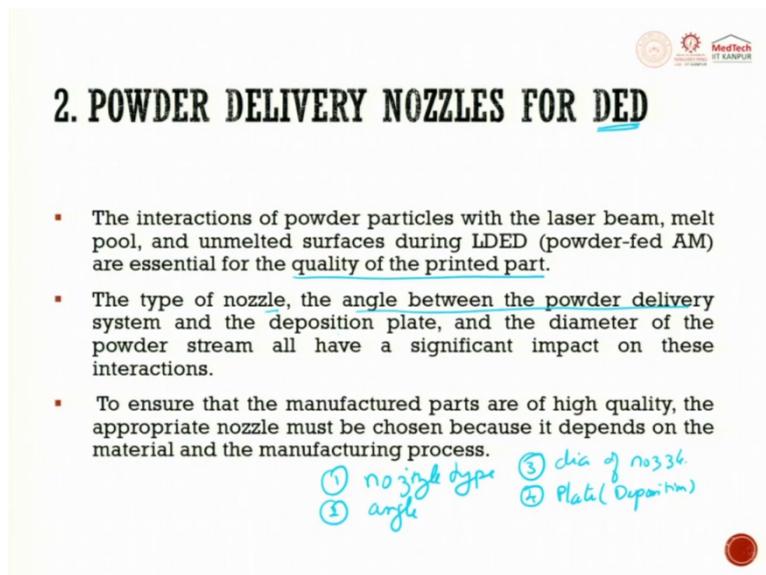
1. CLASSIFICATION OF POWDER FEEDERS

4. VIBRATORY-BASED POWDER FEEDER

- For better control of powder flow, some vibratory bed powder feeders have an oscillating tray with various plates arranged at various angles.
- With a $\pm 1\%$ percent accuracy, the vibratory bed powder feeders can feed a variety of powders at speeds between 8 and 2000 g/min.

For better control of powder flow, some vibration bed powder feeders have an oscillating tray with various plates arranged at various angles. So, what I showed you is a very trivial one, but in reality, you will have various plates and various angles with $\pm 1\%$ accuracy. The vibratory bed powder feeder can feed a variety of powders at speeds from 8 g -2000 g/min, it is very high 2000 g is 2 kg/min.

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2. POWDER DELIVERY NOZZLES FOR DED

- The interactions of powder particles with the laser beam, melt pool, and unmelted surfaces during LDED (powder-fed AM) are essential for the quality of the printed part.
- The type of nozzle, the angle between the powder delivery system and the deposition plate, and the diameter of the powder stream all have a significant impact on these interactions.
- To ensure that the manufactured parts are of high quality, the appropriate nozzle must be chosen because it depends on the material and the manufacturing process.

① nozzle type ③ dia of nozzle
② angle ④ Plate (Deposition)

So, now we will move further and we will see in direct DED energy deposition, powder delivery nozzle. The interaction of the powder particles with the laser beam, melt pool, and unmelted surface during laser directed energy deposition are essential for the quality of the printed part. The interaction of powder particle with the laser beam, here if the flow is very high, the laser spot diameter is low, it moves very fast, you will not have a proper diffusion.

Melt spool creation and unmelted surface during LDED are essential for quality of the printed head, the type of nozzle, the angle between the powder delivery system, and the deposition plate. The diameter of the powder stream all play a very important role. First is nozzle type, the next one is angle, third one is diameter of nozzle, and fourth one is the plate deposition.

All these things are very important, to ensure that the manufactured part are of high quality. The appropriate nozzle has to be chosen, as it depends upon the material and the manufacturing process.

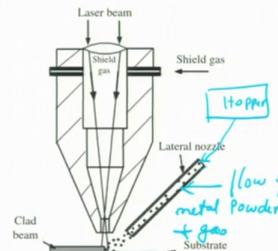
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The slide is titled "2. POWDER DELIVERY NOZZLES FOR DED" in bold black text. Below the title, it states "The delivery nozzles can have two different configurations:" followed by a numbered list: "1. Lateral" and "2. Coaxial". To the right of the list is a hand-drawn diagram in blue ink showing a rectangular box labeled "Hopper" with a vertical line leading down to a conical shape labeled "nozzle". In the top right corner of the slide, there are logos for "MedTech" and "IIT KANPUR". A small red circular logo is in the bottom right corner.

2. POWDER DELIVERY NOZZLES FOR DED

1. LATERAL NOZZLE

- The powder is delivered from the side in the AM process when a lateral nozzle is used, and an inert gas that passes through the nozzle aids in the powder delivery stream while preventing deposit oxidation.



Schematic of a typical lateral nozzle.

E. Toyserkani, A. Khajepour, and S. Corbin, Laser cladding, 1st edition, CRC Press, 2004. <https://doi.org/10.1201/9781420039177>

The delivery nozzle, so hopper, and then you have an attachment as a nozzle. So, the delivery nozzle can have two different configurations, one is lateral, another one is coaxial. This is what is very commonly used as lateral nozzle. In lateral nozzle, you have a hopper, all the powder feed system what we saw, it is all here hopper, so then it gets into a nozzle. So, this nozzle tries to feed the powder at the substrate where the laser is focused, okay.

So, the lateral nozzle is lateral to the laser, the powder is delivered from the side in the additive manufacturing process. When a lateral nozzle is used, an inert gas that passes through the nozzle aids in the powder delivery stream, while preventing deposit oxidation. So, here the lateral nozzle is used and an inert gas passes through the nozzle. So, here there will be two flows, so one is flow of metal powder driven by a gas. So, this gas tries to prevent oxidation happening at the laser matter interaction.

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2. POWDER DELIVERY NOZZLES FOR DED

1. LATERAL NOZZLE

- The lateral nozzle's reliance on trajectory orientation is one of its problems.
- The way the power stream interacts with the melt pool will change if the lateral nozzle is fixed to the laser beam's axis and the trajectory is not linear.
- Due to this problem, some businesses, including Optomec, have created a nozzle that has four lateral nozzles.



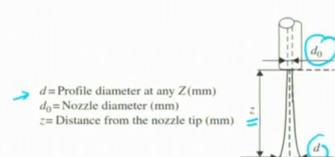
The lateral nozzle reliance on trajectory orientation is one of the problems. The way the powder stream interacts with the melt pool will change if the lateral nozzle is fixed to the laser beam axis and the trajectory is not linear. When you have untoward surfaces like this, so then the way the powder stream interacts with the melt pool will change, if the lateral nozzle is fixed to the laser beam axis. So, if these two are fixed, then you will have this lateral nozzle is fixed to the laser beam axis and then the trajectory is not linear. Due to this problem some business includes Optomec have created a nozzle that has four lateral nozzles.

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2. POWDER DELIVERY NOZZLES FOR DED

1. LATERAL NOZZLE

- As was mentioned in the previous section, the powder delivery system has a significant impact on the quality of AM-produced parts in terms of the powder stream diameter that must be deposited, the stability of the powder feed rate, the speed of the powder particles, and the uniformity of the powder's profile shape.



d = Profile diameter at any Z (mm)
 d_0 = Nozzle diameter (mm)
 z = Distance from the nozzle tip (mm)

Powder feed profile characteristic

E. Toyserkani, A. Khajepour, and S. Corbin, Laser cladding, 1st edition, CRC Press, 2004. <https://doi.org/10.1201/9781420039177>

In lateral nozzle we will try to see some little bit of science, as was mentioned in the previous section. The powder delivery system has a significant impact on the quality of additive manufacturing produced parts in terms of the powder stream diameter that must be deposited, the stability of the powder feed rate, the speed of the powder particles, and the uniformity of the powder's profile shape. All these things are very important.

(Refer Slide Time: 27:48)



2. POWDER DELIVERY NOZZLES FOR DED

1. LATERAL NOZZLE

- The powder stream profile could be described by a parabolic equation, according to research done using a different nozzle with different diameters.

$$d = \lambda z^2 + d_0$$

where d is the profile diameter at any z (mm).

λ is the powder profile's quality coefficient (1/mm), it is valid for a particular range where the powder stream is stable.

d_0 is the nozzle diameter (mm).

z is the distance from the tip of the nozzle to the desired point (mm).



So, the d at the substrate where you have to deposit the material you can find out that in terms of height and nozzle diameter. The powder stream profile could be described by a parabolic equation, why parabolic? It will go something like this parabolic equation, this is the powder feed, depending on the distance it gets dispersed. The laser beam profile could be described by a parabolic equation. According to research done using a different nozzle with different diameter, this is directly proportion to the z^2 .

$$d = \lambda z^2 + d_0$$

where d is the profile diameter at any z (mm), λ is the powder profile's quality coefficient (1/mm), it is valid for a particular range where the powder stream is stable, d_0 is the nozzle diameter (mm), z is the distance from the tip of the nozzle to the desired point (mm).

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2. POWDER DELIVERY NOZZLES FOR DED

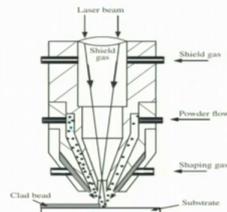
2. COAXIAL NOZZLE

- The coaxial nozzle has the same deposition rates in either direction and greater powder efficiency, which is the ratio of powder deposited on the workpiece to powder provided by the powder feeder at a particular time.
- A laminar powder stream at the nozzle outlet delivers a homogeneous powder stream and high-quality products.
- Focusing on the melt pool ensures optimum part quality and powder efficiency.
- Choosing the correct nozzle tip can create laminar flow, powder stream patterns, and powder focus.
- Powder stream is shaped by a parabola.
- Unlike a lateral nozzle, the powder stream converges and then diverges.

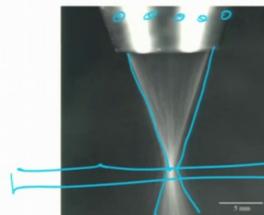


2. POWDER DELIVERY NOZZLES FOR DED

2. COAXIAL NOZZLE



Schematic of a typical coaxial nozzle.



Powder stream at the nozzle exit to a co-axial nozzle.

E. Toyserkani, A. Khajepour, and B. Corbin, Laser cladding, 1st edition, CRC Press, 2004. <https://doi.org/10.1201/9781420009177>

When we try to talk about coaxial nozzle, coaxial means you will have two three nozzles coming out. So, you see here, here is one nozzle, here is one nozzle, they are coaxial to the laser. Coaxial has the same deposition rates in either direction and greater powder efficiency, as compared to that of your lateral nozzle, which is the ratio of the powder deposited on the work piece to powder provided by the powder feeder at a particular time.

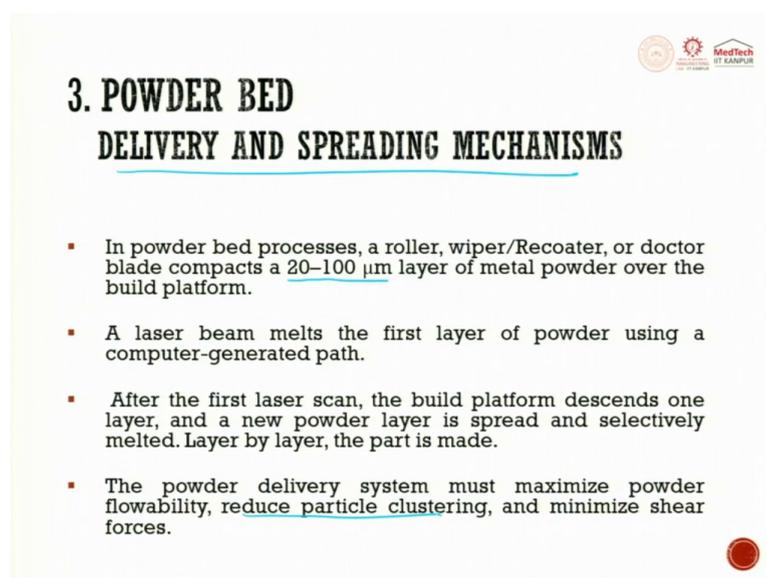
A laminar powder stream at the nozzle outlet delivers a homogeneous powder stream and a high-quality product, a laminar powder stream maintaining is a tough problem. Next is focusing on the melt pool, ensures optimum part quality and the part efficiency, what is melt pool? When the laser hits, so what happens is you will have some amount of melting which happens, so this is called as the melts pool, okay.

So, nozzle outlet delivers a homogeneous powder stream and a high-quality product, focusing on the melt pool ensures optimum part quality and powder efficiency. Choosing the correct nozzle tip can create lamellar flow, powder stream pattern and powder focus. Like you had your TE₁₀ mode, here also what happens when you have these nozzles, you can start playing with it, the powder stream is shaped by a parabola, same thing like your aseptic machine, we are talking about a parabola. Unlike, a lateral nozzle the powder stream converges and then diverges. So, what they say converges and then diverges.

So, you have to find out what is it, so it is focused and then it diverges. So, the powder stream at the nozzle exits your coaxial nature. So, you have to place your substrate here 20-100 μ layer straight location, okay. So, these are coaxial nozzle, if you see here, it is only 2 because it is a 2D.

So, if you have in reality what will happen you will have all around the periphery 1, 2, 3, 4, 5, something like that. So, you have a laser, so shielded gas, then you have nozzle, through this nozzle you will try to have this powder fed coaxially to the work piece and then you do it. Here also, we try to use gas, so this gas purges on top of it and then it tries to do it, see all these freedoms are possible in laser. In electron beam, you do not have this shielding and other things, you just have to do it in vacuum.

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The slide features a title '3. POWDER BED DELIVERY AND SPREADING MECHANISMS' in bold black text. Below the title is a list of four bullet points. The first bullet point describes the compaction of a 20-100 μm layer of metal powder. The second describes the melting of the first layer by a laser beam. The third describes the descent of the build platform and the spreading of a new powder layer. The fourth describes the requirements for the powder delivery system. In the top right corner, there are three logos: a circular one, a gear-like one, and one for 'MedTech IIT KANPUR'. A small red circular logo is in the bottom right corner.

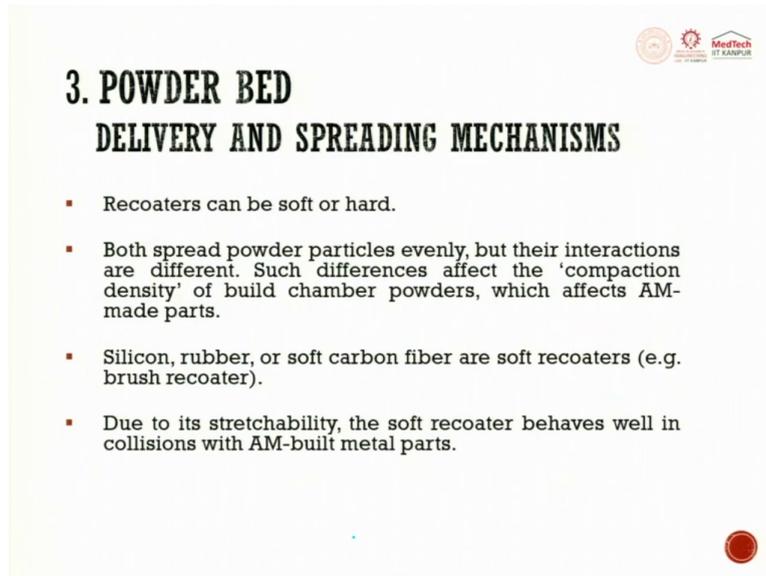
3. POWDER BED DELIVERY AND SPREADING MECHANISMS

- In powder bed processes, a roller, wiper/Recoater, or doctor blade compacts a 20–100 μm layer of metal powder over the build platform.
- A laser beam melts the first layer of powder using a computer-generated path.
- After the first laser scan, the build platform descends one layer, and a new powder layer is spread and selectively melted. Layer by layer, the part is made.
- The powder delivery system must maximize powder flowability, reduce particle clustering, and minimize shear forces.

Now, we are moving into the next section where we talk about delivery and spreading mechanism. So, in powder bed process a roller viper/recoater or doctor blade compacts of

metal powder over the build region. A laser beam melts the first layer of the powder using computer generated path. After the first laser scan, the build platform descends one layer, and a new powder layer is spread and selectively melted. Layer by layer, the part is made. The powder delivery system must maximize powder flowability, reduce particle clustering and minimize shearing forces.

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The slide features a title '3. POWDER BED DELIVERY AND SPREADING MECHANISMS' in bold black text. Below the title is a bulleted list of four points. The slide also includes logos for 'MedTech' and 'IIT KANPUR' in the top right corner and a red circular logo in the bottom right corner.

- Recoaters can be soft or hard.
- Both spread powder particles evenly, but their interactions are different. Such differences affect the 'compaction density' of build chamber powders, which affects AM-made parts.
- Silicon, rubber, or soft carbon fiber are soft recoaters (e.g. brush recoater).
- Due to its stretchability, the soft recoater behaves well in collisions with AM-built metal parts.

The powder bed fusion is a complex process, so it is important to have a homogeneous powder thickness in each layer, because whatever powder gets fallen down, it has to be spread, it has to be spread by a doctor's blade or by a recoater to maintain the uniform thickness, and in one layer also you should have, say for example when we try to have a powder and then you will have lot of places, so that also has to be optimized such that we get a good quality output.

The inert gases are introduced into the metal chamber to prevent oxidation of the melt pool and remove condensate. So, melt pool always has a possibility of attracting oxygen and the oxygen gets diffused into the melt pool, we try to avoid it. The density of laser powder bed fusion parts depends on the speed of the counter rotating roller, roller properties, powder bed layer thickness and powder particle size all these things try to dictate the powder quality. Trial and error techniques, mathematical modelling and simulation provides information on the phenomena.

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3. POWDER BED DELIVERY AND SPREADING MECHANISMS

- Recoaters can be soft or hard.
- Both spread powder particles evenly, but their interactions are different. Such differences affect the 'compaction density' of build chamber powders, which affects AM-made parts.
- Silicon, rubber, or soft carbon fiber are soft recoaters (e.g. brush recoater).
- Due to its stretchability, the soft recoater behaves well in collisions with AM-built metal parts.

Recoater can be a soft or a hard blade or a roller. Both spread roller particles evenly but their interaction are different, such differences affect the compaction density of build chamber powder which affects the additive manufactured part. Silicon rubber or soft carbon fibre are often chosen for soft recoaters. Due to its stretchability, soft recoaters behave well in additive manufacturing while building parts.

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3. POWDER BED DELIVERY AND SPREADING MECHANISMS

Illustration of a LPBF process system setup

I. G. E. Gore, N. Branch, T. Roman, E. Orange, K. Wayne, and R. A. Gore, "United States Patent (19)," no. 19, 1998.

So, these are the recoaters, main tank hopper, so what they do is these recoaters move on top of it and it tries to coat a very small thickness. They also make sure that the powder particles

are kept close to each other and the space between is optimized such that when the laser hits it melts and it does not generate any porosity there.

So, previous layer, you can see initial plate, then spreading of powder has happened. We use argon gas to make sure that oxidation does not happen, this is a laser, this is a scanner. So this is what is a limiting unit because mechanically it has to sweep on a floor and then get. So, these are all the melt zone and by the way, this is one layer, in one layer you see islands of hatch patterns are created for generating a good quality output.

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3. POWDER BED DELIVERY AND SPREADING MECHANISMS

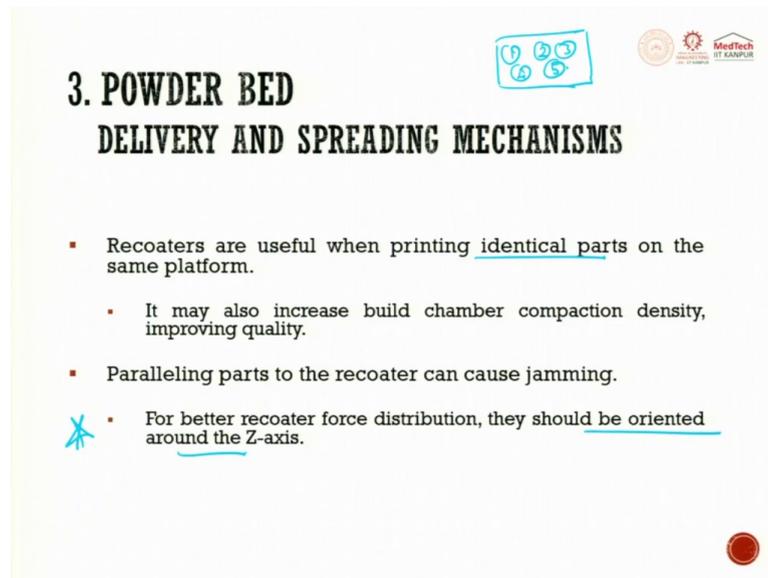
- This type of recoater may be ideal for concurrent additive manufacturing of different parts in the same build chamber.
- Hard recoaters made of HS steel or ceramic exert pressure on the powder bed. Unlike soft recoaters, this type prevents part deformation.
- When the recoater collides with a wrapped part, it jams or parts are separated from the support structure and dragged across the powder bed. The latter damages the whole structure.

Recoater → soft →
 → hard → non-uniform spreading
 ↓
 Crack + break

The type of recoater may be ideal for concurrent additive manufacturing of different parts in the same built chamber. Hard coaters made of high-speed steel or ceramic exerts pressure on the powder bed. Unlike soft, this type prevents part deformation. Recoater is of two types soft and hard, so hard means there is a possibility that you can have somewhere non uniform spreading.

But whereas in soft you will always have uniform spreading. When a recoater collides with a warped part it jams or parts are separated from the support structure and drags across the powder bed. So, we will always try to avoid using it, so this will crack and break the part even hard, so that is why we always go for soft recoaters.

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The slide features a title '3. POWDER BED DELIVERY AND SPREADING MECHANISMS' in bold black text. To the right of the title is a blue hand-drawn box containing the numbers 1, 2, 3, 4, and 5. In the top right corner, there are two logos: one for 'MedTech IIT KANPUR' and another circular logo. The main content consists of four bullet points, with the last one marked by a blue asterisk. The text 'identical parts' and 'around the Z-axis' are underlined in blue. A red circular logo is located in the bottom right corner of the slide.

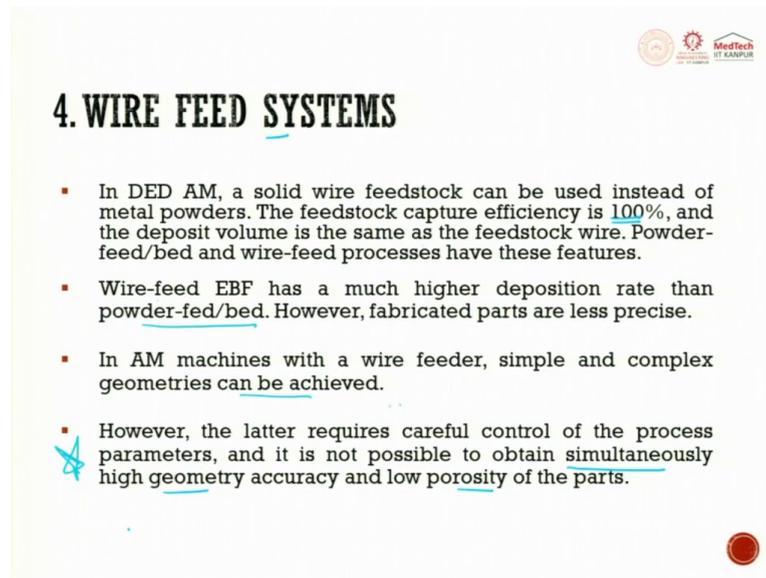
3. POWDER BED DELIVERY AND SPREADING MECHANISMS

- Recoaters are useful when printing identical parts on the same platform.
 - It may also increase build chamber compaction density, improving quality.
 - Paralleling parts to the recoater can cause jamming.
- * For better recoater force distribution, they should be oriented around the Z-axis.

So, the recoaters are useful when printing identical parts on a same platform, it may also increase build chamber compaction density and improve quality. Paralleling parts to the recoater can cause jamming, for better recoater force distribution that should be oriented around the z-axis.

So, this is also an important point which you are trying to do and here when we are trying to do in additive manufacturing, we can also have various parts simultaneously getting built and then you detach, then you try to do an assembly. So, this is what we are trying to talk about when printing identical parts on the same platform. 1, 2, 3, 4, 5 are identical, you can have 1, 2, 3, 4, 5 as different, it may also increase the build chamber compaction density and improve quality.

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4. WIRE FEED SYSTEMS

- In DED AM, a solid wire feedstock can be used instead of metal powders. The feedstock capture efficiency is 100%, and the deposit volume is the same as the feedstock wire. Powder-feed/bed and wire-feed processes have these features.
- Wire-feed EBF has a much higher deposition rate than powder-fed/bed. However, fabricated parts are less precise.
- In AM machines with a wire feeder, simple and complex geometries can be achieved.
- However, the latter requires careful control of the process parameters, and it is not possible to obtain simultaneously high geometry accuracy and low porosity of the parts.

The last process which we are discussing is going to be wire fed system. In directed energy deposition, additive manufacturing is a solid wire feed stock, powder can also be used, wire also can be used, instead of metal powders, why? because of this all the problems of agglomeration not improper feeding, we converted into a wire, wire can be easily extruded.

So, the feed stock capturing efficiency is 100% in wire feed system and the deposited volume is the same as the feedstock wire. Powder fed/bed and wire fed processes have these features, so they almost have the same feature like that of the powder. Wire fed electron beam fusion method (EBF) has a much higher deposition rate as compared to that of powder bed.

However, fabricated parts are less precise when we use wire as a starting material, even though you use electron beam. Additive manufacturing machines with wire feeder are simple and complex geometries and can be easily achieved. However, the later requires a careful complex shape that requires a complex careful control of the process parameters and it is not possible to obtain. Simultaneously, high geometric accuracy starting material and wire assess is a very important point, so please make a note, okay.

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4. WIRE FEED SYSTEMS

- Wire-based DED machines are used when pore-free parts and dimensional accuracy are not important criteria for production.
- Depending on the energy source used, wire-feed AM can be laser-based, arc welding-based, or electron beam-based.
- EBF is promising for aerospace applications because it can be done in a vacuum. It is equipped with a wire feeder avoiding the use of powders difficult to be contained safely in low-gravity settings

Wire based direct energy deposition machines are used when pore free parts and dimensional accuracies are not important criteria of making additive manufacture, but depending upon the energy source used, wire feed additive manufacturing can be laser based, arc welding based, or electron beam-based. Here, electron beam fusion is promising for aerospace application because, it can be done in vacuum, the wire also can be done in vacuum. It is equipped with wire feeder avoiding the use of powder and then powder spreading difficulty.

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4. WIRE FEED SYSTEMS
POWDER VS WIRE FED SYSTEMS

Type of material	Process	Layer thickness (µm)	Deposition rate (g/min)	Dimensional accuracy (mm)	Surface roughness (µm)
Powder	Laser cladding	100 to 1000	1 to 30	±50 to ±500	5 to 50
	LPBF	20 to 100	n/a	±25	9 to 10
	Selective laser sintering	50 to 75	n/a	±10	14 to 16
Wire	DED	100 to 1000	12	±25 to ±500	~20
	Arc welding	~1500	12	±50 to ±500	200
	Electron beam (EBF)	n/a	Up to 330	Low	High

So, now here let us compare between layer thickness deposition rate, dimensional accuracy, and surface roughness. Powder can be used for laser cladding, you can try to have layer

thickness from 100 μ to 1000 μ , deposition rate will be 1-30 g/min, dimensional accuracy will be ± 50 -500 mm, surface roughness will be 5-50 μ .

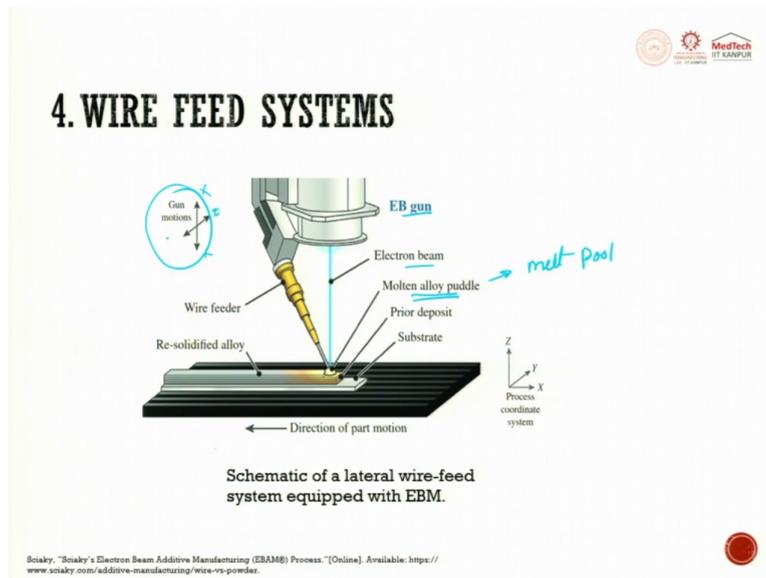
Then, when we talk about laser powder bed fusion, you can have a layer thickness of 20-100 and deposition rate is not applicable here, and dimensional accuracy what you get is ± 25 and the roughness can vary up to 10 μ . When we talk about selective laser sintering method, the layer thickness can go from 50-75, the feeding mechanism is not there because it tries to spread by a recoater, the dimensional accuracy can be up to 10 mm and here you will try to have the surface roughness from 40-16.

When we talk about directed energy deposition here, the layer thickness can vary from 100-1000 the deposition rate will be 12 g/min and then dimensional accuracy will be ± 25 - ± 500 μ , the roughness will be approximately 20 μ . And we talk about arc welding, so this is all done as far as powder and here we have direct energy deposition, arc welding, and electron beam.

So, here you can have arc welding in which about 1000-500 μ will be the layer thickness, the deposition rate will be 12, the dimensional accuracy is almost the same of DED and the roughness goes very high up to 200 μ . When we talk about electron beam the layer thickness is for wire it is not applicable, then it can go up to a deposition rate of 300 g/min, the dimension accuracies are extremely low here and the surface roughness is very high more than 200 μ .

So, through this table you are able to compare with respect to starting material, whether it is a powder or a wire, which process to use, what are all its performance with respect to various process parameters.

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So, this is a wire fed system, so you have a wire which is getting fed here, a laser which is getting hit here or an electron beam. Then molten pool, so this is the alloy which is always called as melt pool, this is molten alloy puddle, then you will have prior deposition.

So, this is prior deposition and this is substrate, so you are trying to do the previous layers. So, this is re-solidified alloy, this is how the wire is fed and here you will have the pool and other things, so this is the direction of the part. So, the gun can move up and down, x and y, so it can move in the x direction, it can move in the z direction, or it can move in the y direction.

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The slide lists characteristics of wire feed systems. A diagram shows a wire being fed into a laser beam, creating a melt pool. The title '4. WIRE FEED SYSTEMS' is at the top. Logos for MedTech IIT Kanpur and Sicaly are in the top right corner.

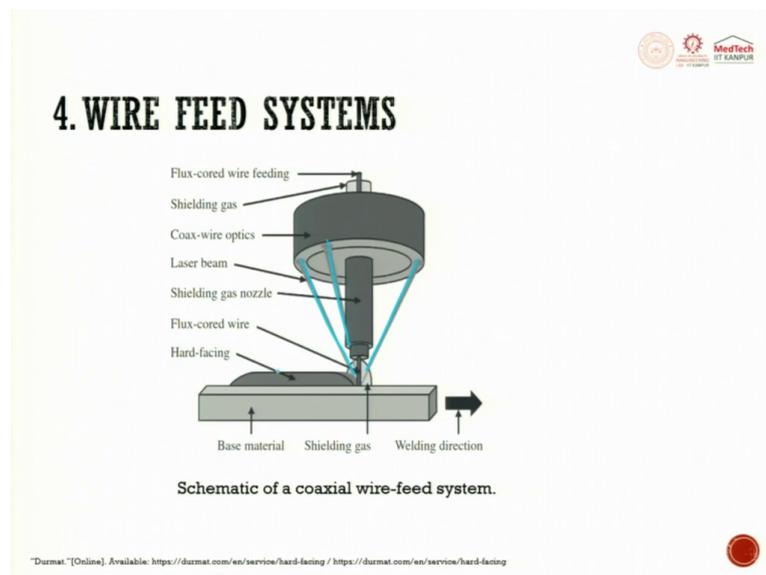
- This type of AM machine can have a lateral or coaxial wire feed system, which affects part quality.
- The second setup is Omni directional.
 - The laser beam is split into three beams and focused on a circular focal point.
- The optical elements' precise location centers the wire feed in the laser beam.
 - This configuration allows the wire to be fed into the center of the laser-generated melt pool.
- Contact force must be kept constant to ensure AM part quality.
 - Wire-fed AM isn't a good choice for smooth surfaces.
- This technology can't make complex parts.
 - Making complex shapes may be difficult with a fixed contact force and a mobile feeding mechanism.

So, this type of additive manufacturing means to say that wire fed systems can have lateral or coaxial wire feeding mechanism just like your powder feeding which can be lateral and coaxial. The second setup is omni directional. The laser is split into three beams and focused on a circular focal point; we are now trying to play with the laser.

So, the laser beam is split into three, and then all these things get focused on top of a substrate, this is your substrate, okay, so this is a laser. So, the laser beam is split into three beams and focused on a circular focal point. The optical element's precise location centers the wire feed in the laser beam. This configuration allows the wire to be fed in the centre of the laser generated melt pool.

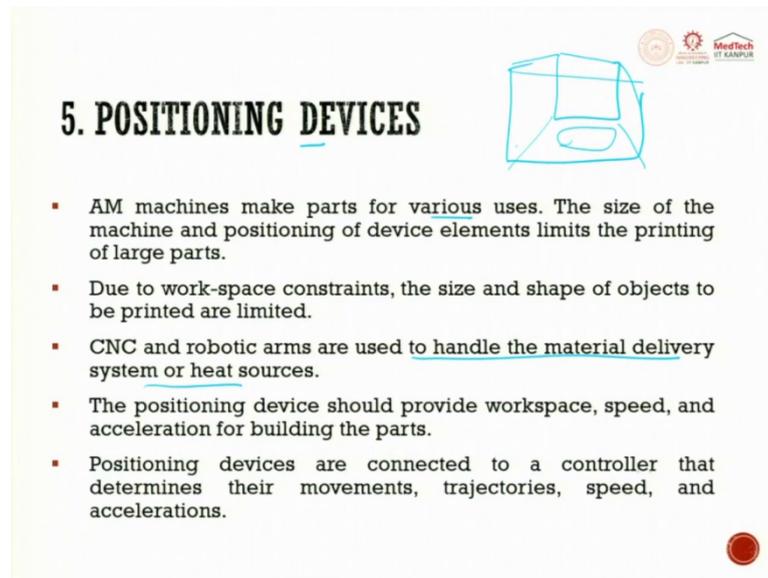
Contact forces must be kept constant to ensure additive manufacturing produce a good quality output, this technology cannot make complex parts with respect to wire frame, because the wire itself when it gets melt, it will not be very small particles, it will be a large droplet, so complex parts cannot be made through this.

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So, this is what is the laser which I said you have, splitting it, and you are trying to focus it. So, this is a flux core wire feeder, then you have shielded gas which is there, then you have a coaxial wire optics, then laser beam, three laser beams, it tries to hit at a surface. So, shielded gas flux coat wire is there and then hard facing are getting deposited.

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5. POSITIONING DEVICES

- AM machines make parts for various uses. The size of the machine and positioning of device elements limits the printing of large parts.
- Due to work-space constraints, the size and shape of objects to be printed are limited.
- CNC and robotic arms are used to handle the material delivery system or heat sources.
- The positioning device should provide workspace, speed, and acceleration for building the parts.
- Positioning devices are connected to a controller that determines their movements, trajectories, speed, and accelerations.

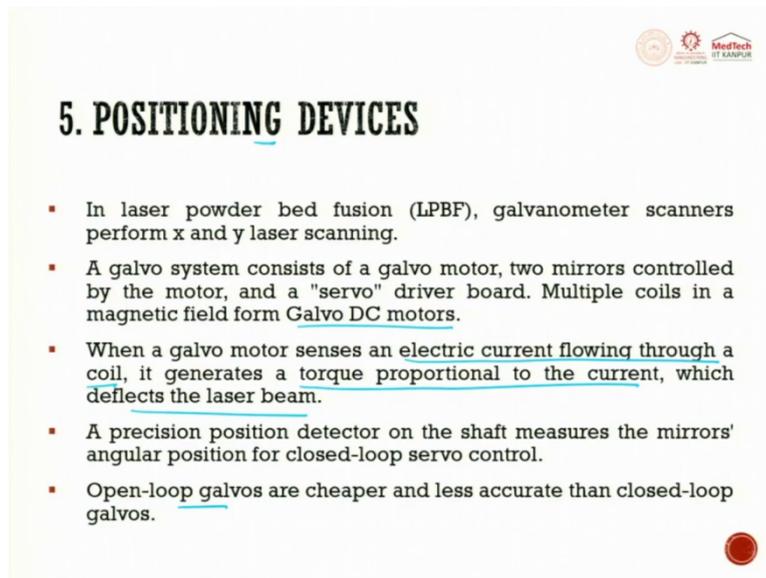


The last part of our discussion with respect to different systems is going to be the positioning device. Additive manufacturing machine makes parts for various uses, the size, shape, and the machine all tries to depend on the positioning. Positioning tries to dictate the quality of the output due to work space constraint. What is workspace constraint?

This is a work space, so within which you start developing the output, so here is the table. So, this is the workspace, the workspace constraint the size and the shape of the object to be printed. CNC and robotic arm are used to handle them, material delivery for wire in a big way.

So, when you use a five-axis-robot, it tries to generate a complex surface, complex surface means a very curvature surface, but the accuracy is poor. The positioning device should provide work space speed and acceleration for the building of parts. Positioning device are connected to the controller that determines their movement, trajectory, speed and acceleration.

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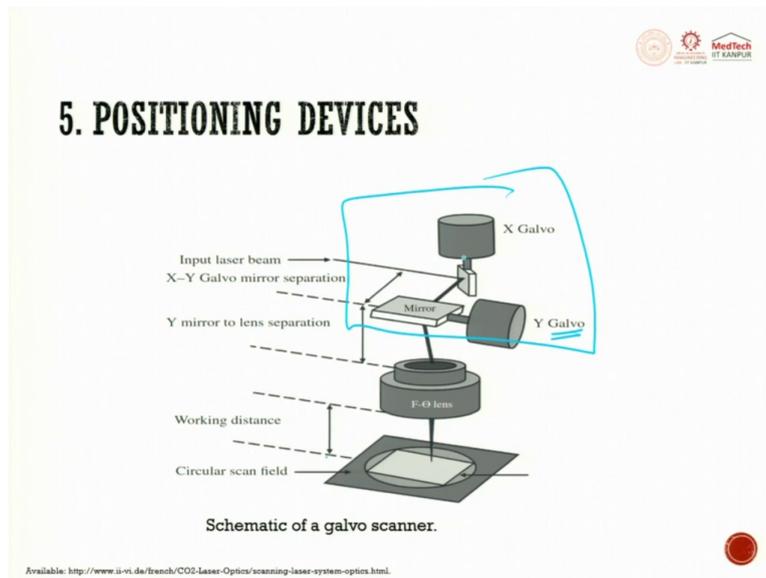
5. POSITIONING DEVICES

- In laser powder bed fusion (LPBF), galvanometer scanners perform x and y laser scanning.
- A galvo system consists of a galvo motor, two mirrors controlled by the motor, and a "servo" driver board. Multiple coils in a magnetic field form Galvo DC motors.
- When a galvo motor senses an electric current flowing through a coil, it generates a torque proportional to the current, which deflects the laser beam.
- A precision position detector on the shaft measures the mirrors' angular position for closed-loop servo control.
- Open-loop galvos are cheaper and less accurate than closed-loop galvos.

In the laser powder bed fusion, galvanometer scanner positions x and y, which is a positioning device. The galvo system consists of a galvo motor, two mirror controlled by a motor and a servo drive board. Multiple coils in a magnetic field forms a Galvo DC motor, so positioning is very important. When a galvo motor senses an electrical current flow through a coil, it generates a torque proportional to the current while deflecting the laser beam.

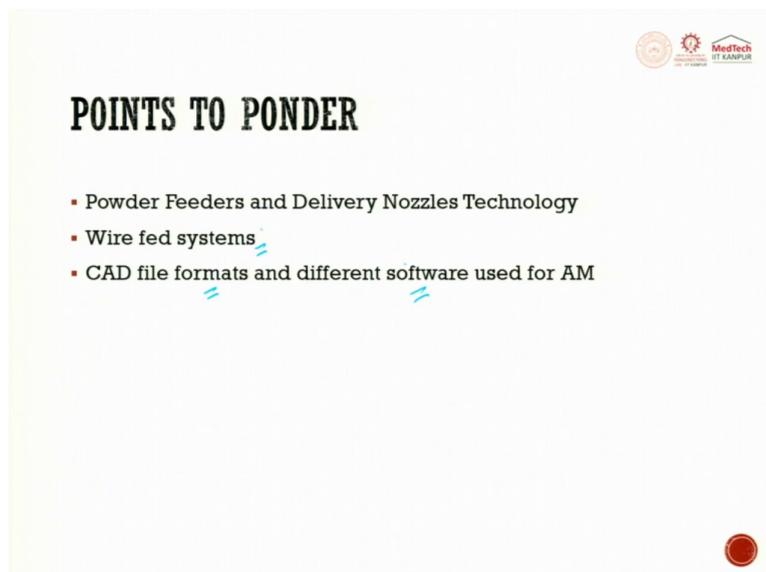
This is very important, electric current flowing through the coil which generates torque, and this tries to deflect the laser beam. The precision position detector on the shaft measures the mirror angular position for a closed loop system. We can also use open loop system which is economical, but you have to compromise your quality.

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So, this is what is the galvo. So, this put together is called as a galvo system. You have a x galvo, y galvo, then it passes through f theta lens which tries to give you a focus anywhere on a single plane. So, this is the working distance, this is the x mirror to length separation, this is the x-y galvo separation, and this is the x separation. This is a positioning device which is exhaustively used in laser.

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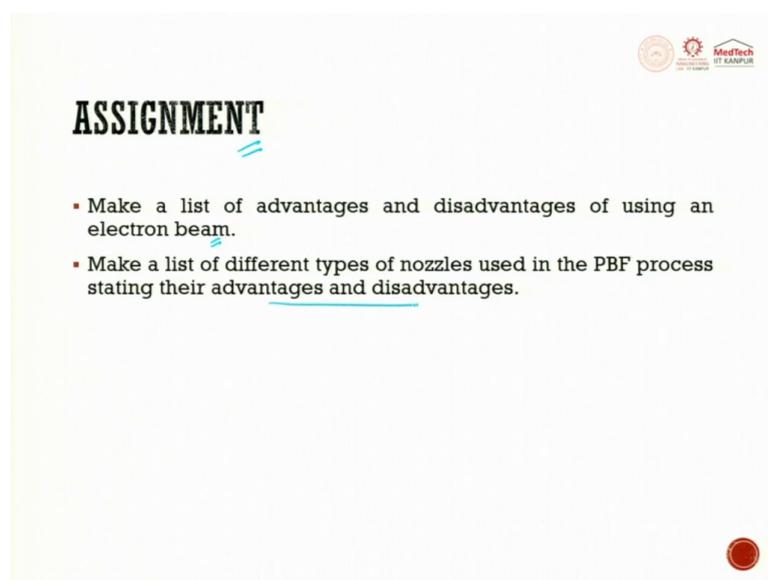
So, points to ponder. In this lecture, we saw how are powder getting feed, how are wire getting feed, and how is it happening through a nozzle. We also try to see the positioning device which plays an important role in generating a good quality output. So, here I would

like to give assignments, the first assignment is going to be try to understand the wire feeding mechanism in arc welding or in fuse deposition, how is it controlled by a controller by touch of a button? so that is one.

Second thing is, if you can start looking into a wire feeding mechanism, which is used in your tailoring machine, when you start moving the pedal, you can see the wire or the thread which is getting forced which feeds continuously, try to understand how a tailoring machine works, that means to say in particular thread getting fed. If you see that, you will try to understand and appreciate the complexity involved in wire fed mechanisms.

And also, you can look at how are the CAD file formats and different softwares are used in accommodating powder feeding, delivery of the nozzle and wire fed systems.

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ASSIGNMENT

- Make a list of advantages and disadvantages of using an electron beam.
- Make a list of different types of nozzles used in the PBF process stating their advantages and disadvantages.

The assignments which are given in the previous lecture, you can add. Make a list of advantages and disadvantages of using electron beam. Also, make a list of different types of nozzles used in the powder bed fusion process, stating their advantages and disadvantages. With this, we are coming to an end about the basic understanding of the processes. Thank you.