Welding Processes
Professor Dr Murugaiyan Amirthalingam
Department of Metallurgical and Material Engineering
Indian Institute of Technology, Madras
Laser Welding Process Part 02

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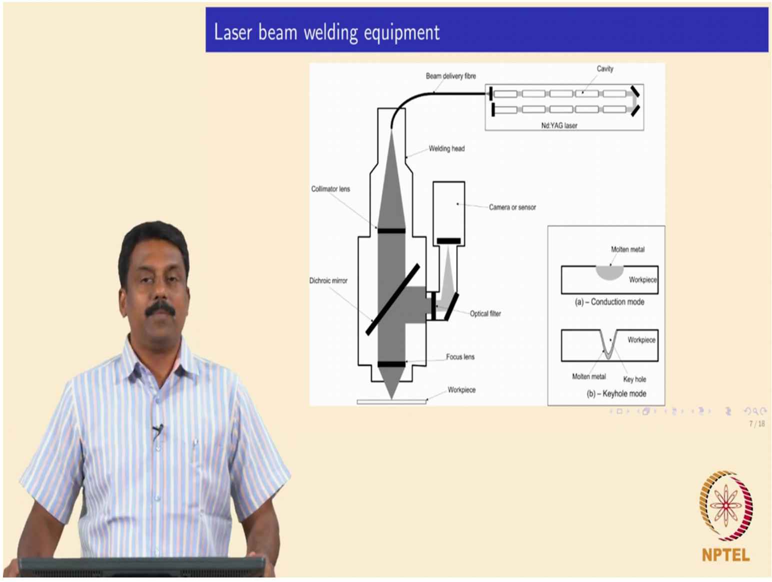

So typical welding station using laser is also again very simple okay, so one of the schematic which I drew for the laser welding setup in one of the labs in Europe ok where I was working for several years, and it had an Nd-YAG laser ok of maximum 4 kilowatts right, so 4 kilowatts and we had about 10 Nd-YAG rod source ok, so it would be using 400 watt power or so right. And so if you look at the entire setup so this is about close to 5 meters or so and it will be about 2 meters in height, about 1.5 meters in wide ok and inside that you will have Nd-YAG rods and each rod should have its own pumping source and we used to have huge flash lamps ok.

So generally we can generate either with the pulse or with continuous lamps ok so it becomes pulse laser or continuous wave laser. And so the entire setup is extremely complex because each system should have its own pumping source, lamps, Nd-YAG rod crystals and then if one of the rods are broken or one of the rods are not working fine then you may not get 4 kilowatts okay so obviously you will reduce 400 watts if one of the rods are not working and if the lamps are broken pumping source, again you will not put any laser because unless you send the pumping laser and then you cannot send you cannot generate any laser right.

So you need to have a separate cooling because when the lamps are burning and the system must be cool because you have generated a lot of heat right, otherwise entire system can be heated up and can lead to various failure. So you need to circulate water for entire cooling and the laser source itself would need such a big hall for Nd-YAG including cooling, including the power source generated for the labs and everything. So the moment you have laser, and laser now once you have a beam and we do not have any problem, you can transport the laser beam using fibre-optic cable ok, laser light can be transported using beam delivery cable to the welding oxidation right.

And the moment you have been delivered then you also need to have an optical system to focus and defocus as well as to collimate if there is a diversion small diversion happens with beam delivery, then we also have some collimated as well that is it. Okay so the lenses, we will have to use different lenses built on the wavelength example, CO2 lasers wavelength what you look at it in this case.

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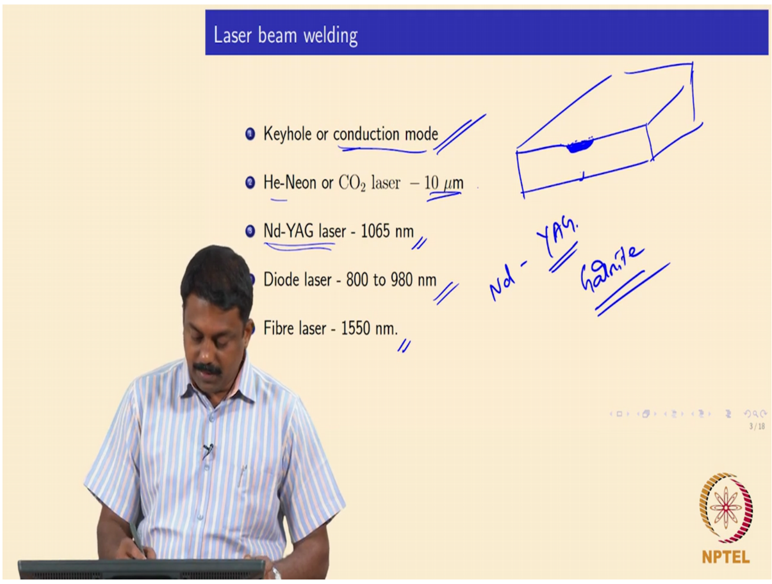

So 10 micrometres okay, so we cannot use normal optical lenses to focus 10 micrometres large wave length, so we also use metallic lenses ok. So for CO2 lasers generally we use metal surface, generally the copper coated with gold ok, so we use the metal lenses to focus the lasers coming out of CO2 gases. An Nd-YAG source the wavelength is near infrared so we can use normal optical lenses for Nd-YAG where as in helium neon and CO2 lasers then he will have to use some special metal lenses for focusing the beam. So once you have lasers and I can have optical system to focus it on to the work piece, is not it? Right.

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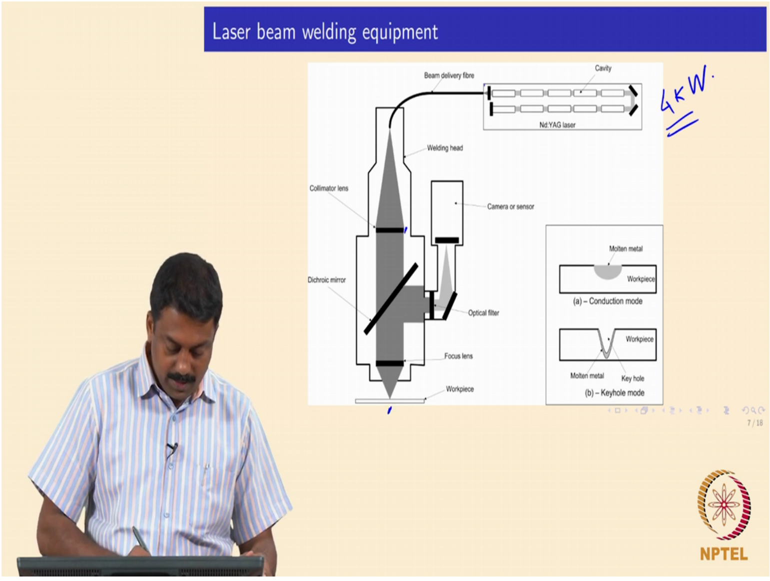

And the part size or laser diameter can be made into a very narrow using the focusing lens safer example, we can get spot size of a millimeter for a 4 kilowatts laser using a proper optical focusing system that means that entire 4 kilowatts can be focused in 1 millimetre diameter. So obviously when you look at the power distribution of the laser okay so suppose if you want to focus a kilowatt onto a 1 millimetre, you may never get 4 kilowatts throughout the diameter of the 1 kilowatt the 1 manna, you will always have power distributed in Gaussian manner ok. So if this is distance or diameter ok, so this is 1 meter or 1 manna or so. So the average power will be for kilowatt ok, so you will have a Gaussian distribution.

The centre of this part laser part will have maximum power and you will have a Gaussian decay when you go out of the surface, it is same as when you see it in laser welding also right, the power distributed is always bell shape ok. So once you have laser focused or basically you can also have manipulation for the worktable so that we can move the work piece in 2 directions X and Y or even Z, or if you move in Z obviously Z becomes your focal point ok. And in this setup we also had another mirror setup so that now we can also reflect whatever happens are the work piece into a camera. Okay, so and this camera is set up in such a way that the mirror sees exactly how the laser sees the workplace ok.

So the advantage of that is suppose if you want to look at the melt pool during welding right, and if you want to observe how the keyhole forms right, so then we will have to see how the laser sees the work piece right. So we will have a mirror setup and this mirror reflects the light from the work piece to the camera and it is a 45 degree mirror right, so laser somewhere but we can have sort of somewhere and which can reflect the work piece surface onto a camera lens ok. We can make the videos and I will show these videos in subsequent slides okay.

So using the laser power and we can either have full penetration wells in keyhole wells, and you can also reduce the power so that the laser does not penetrates fully and we just heat up the surface and then we can do welding in conduction mode as well. And conduction mode is very widely used for cladding applications or (())(7:55) depositions, or if you do not want to melt the entire layer for some of the thin sections thin material, low-thicknesses you do not need to form keyhole ok, so you can just melt and then do a welding in conduction mode right. It is clear how the experimental setup work okay, I will show you the video of this experiment setup and then we will go back, we will come back to this slide.

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Okay so the schematic I showed you is the lab in Europe in Netherlands in a place called Delft. So this is the optics setup okay, so the lens is inside somewhere over there right, and the laser comes along this after getting focused by the optical lens get over there. And the laser is the laser source is kept one floor above ok, so right above this floor right and there is a sticker outside the door, it says that "do not stare at the laser with remaining your eyes, with remaining of whatever left in your eyes" so you cannot see right. So when you look at the laser, the moment you look at with your bare eyes you go blind instantly. The radiation is so powerful that it can burn your pupils, instantly it reprises ok so because of the radiation we go blind just no time.

So we need proper protection eyeglasses even when you go in when the laser is operational, and the power of laser is so huge that we cannot imagine ok. So you may think that it is invisible, so when you use Nd-YAG if you look at it you cannot see because the wavelength is beyond visible spectrum, you will not see the wave is actually operating because our eyes cannot recognize ok. So now what we are discussing is okay so the laser source is in the 1st floor and it is sent by the optical cable and through these optics it is collimated and then focused and you see over there a red spot, it is not actually laser it is actually a pointer.

This is used to position the sample and this pointer locates the exact position of the laser which is coming out and this is Nd-YAG ok so when laser beam is there you do not see anything because Nd-YAG wavelength is how much? Refer, what is the wavelength of India laser? 1058 nanometres right… yeah 1065, 1058 nanometres ok. So when the laser comes in you do not see the beam right, so what we are going to look at is so this blue cable is actually cooling system cooling air, it is actually air cooled system. And you may also have argon cooling as well or argon backing as well shielding to avoid the oxidation generally because the heating grid is so high you do not need any protection right.

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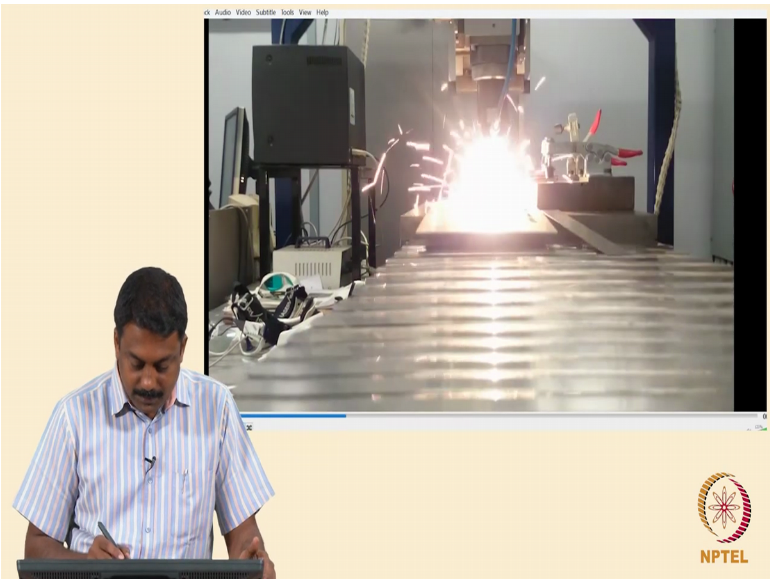

So this is actually compressed gas, this is used for cooling of optics otherwise you may also end up heating of the optics as well right. So now what you are seeing over here, there is a sample here right so there is a tiny cantilever sample be placed and you see over here, yeah so welding is done. So in this case the table can be moved in X and Y direction and by moving in Z direction we can change the focal point right. The focal distance now is 55 MM, and you can also change the power or the amount of energy transferred to the work piece, the change in the focal distance right. So because if you are defocusing the laser, so obviously the power distribution also changes.

The Gaussian distribution I showed you that is when it is in full focused, the full focus is actually on the sample surface, if you defocus it and if it is 4 kilowatt in fully focused condition and it may be 3 and 3.5 kilowatt depending on how you have defocused your beam right ok. So it is clear the schematic, it actually works, and because of this very good manipulation we can play around the laser is much easily okay, so one of the thing is we can make the optics much more simple, and in this case the laser is mounted onto a CNC table. Nowadays we can also mount the laser head into a robot as well ok, and you do not need very high payload because there is no real momentum for laser beams right, so it cannot be manipulated lasers much easily right.

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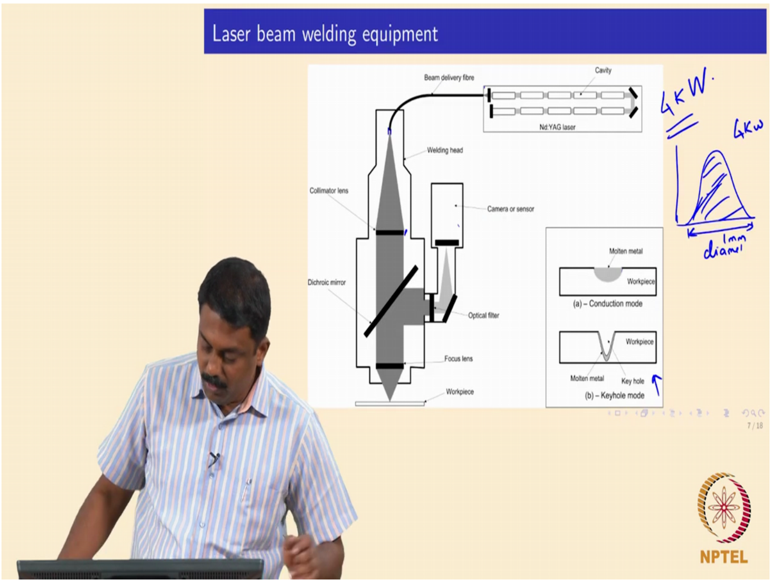

So now we will go back, so what you just saw over here is we saw a summary here on the table. So the entire thing and this was actually in the roof and then we had such a big optics, and we saw laser welding is happening somewhere here. In this case in keyhole mode because we are welding in 4 kilowatts. And if you welding it in few hundred watts or few say 200 watts or 300 watts and you may not see that firecrackers, so it will be just seeing the heating of the surface then you will end up doing a conduction mode welding ok. Okay so now we will also look at laser’s point of view because we also have a mirror assembly and which can reflect whatever is happening over here to a camera and we have generally an high-speed camera attached to that system so that we can see in laser’s point of view right.

So then we can understand so what is happening when the laser beam is actually impinged on the surface, how it melts, how the keyhole is formed right.

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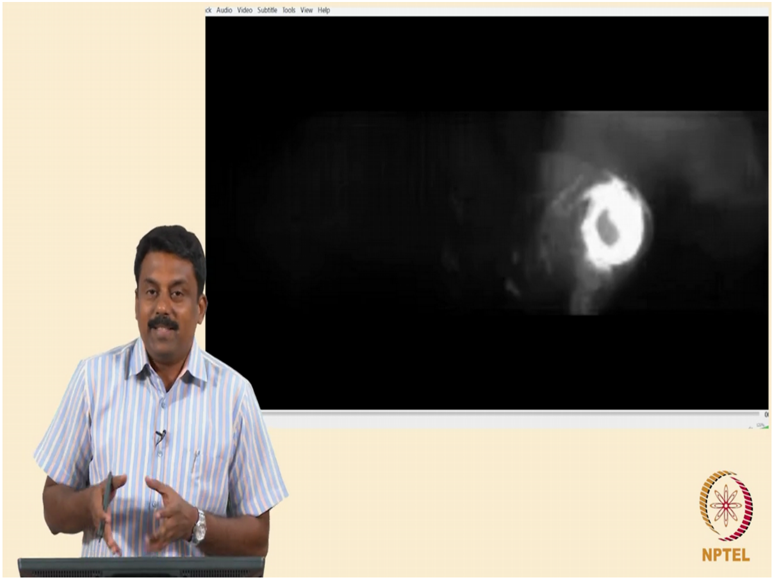

So the laser sees the work piece like this, so what you see over here is illumination by the interaction of laser with the work piece okay, so this is about a 0.8 millimeter thick plate from here to here, and what do you see over here is the keyhole ok. So we are looking how the laser says laser's point of view top of the surface okay like this. Okay so what do you see over here is the top of the keyhole and then you see over here surrounding this region and this is the molten material.

And this keyhole is actually formed because of this evaporation, we will see the keyhole dynamics in the subsequent slides. And because of the vapour pressure and the recoil pressure, the pressure ejected by the pressure of laser going vapour going from the surface would also create a cavity forming this keyhole. And then because of all the severe heat generation, you end up melting the region surrounding the keyhole. And you can see that, see this so this is your molten pool right and the keyhole stability is now is if affected severely because keyhole is not stable, it is all the time changing because of the imbalance in the force that are happening that are generated in the cable yes, you see that.

So we are looking at in laser's perspective, so laser spot size is somewhere very tiny only so in this case we use laser spot of 800 microns and this size will be about 5 MM, the illuminated region and the melt pool can go up to 15-20 MM or so right, it is clear. So the molten pool can always take the shape of tear drop shape, and because of the severe temperature gradient that is prevailing during welding. You see this, this is the molten region in the pool and when the structure solidifies so you will have the columnar growth that is happening from the fusion boundary, so fusion boundary is somewhere over here, is not it? So this is the molten pool boundary, and then when it solidifies obviously it will solidify (()) (17:24) right, good, so any questions?

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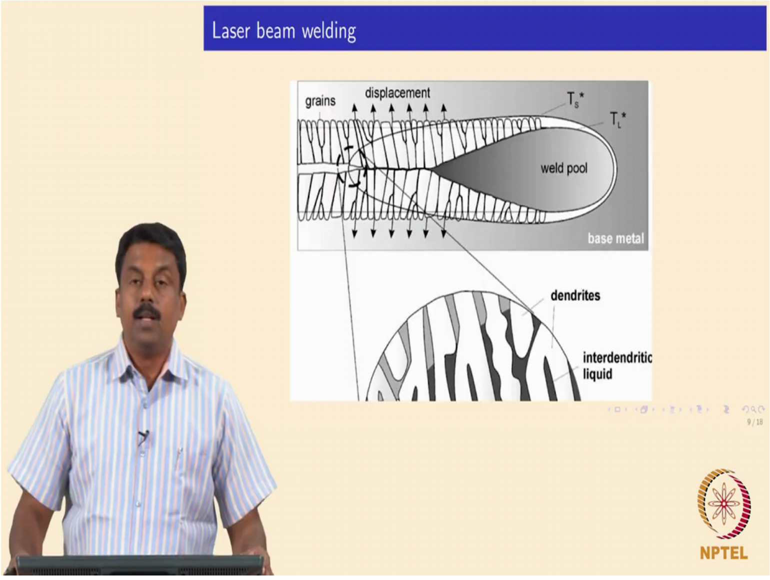

So what is over here with laser's perspective is somewhere here we have a keyhole, is not it? And this is illumination and the keyhole and you have a molten pool forming a teardrop shape right. And is that video the laser source is moving in this direction, so when the laser source is moved so obviously the heat extraction from the adjoining regions would lead the pool solidify in columnar manner from the fusion boundary towards the well centre line. So the solidification is actually determined by the temperature gradient, generally the temperature gradient during welding is extremely steep. So the grinds will start solidifying in columnar manner from the fusion boundary towards well centre line, yeah.

And because of the steep temperature gradient, the well pool shape is always teardrop, we will do not go into the details of that because we will see it in welding metallurgy. So now we can assume that and because of the temperature gradient that are prevailing in the well pool the teardrop shape, and when the heat is extracted and it will start solidification starting from fusion boundary towards the well centre line and the grinds will solidly in columnar manner. And due to that you always have segregation because this region solidifies in the end. And you may also have the tensile stress developing because of the solidification shrinkage.

So solidifying grinds would be shrinking along this direction, but because of the constraints mechanical constraint offered from the heater of its own and that is always tensile stress acting to compensate the solidification shrinkage, so the well centre line will always be in a very high tension right, it is clear good. And it was thin so far and the basic welding, whereas we will move on to the physics of this process.

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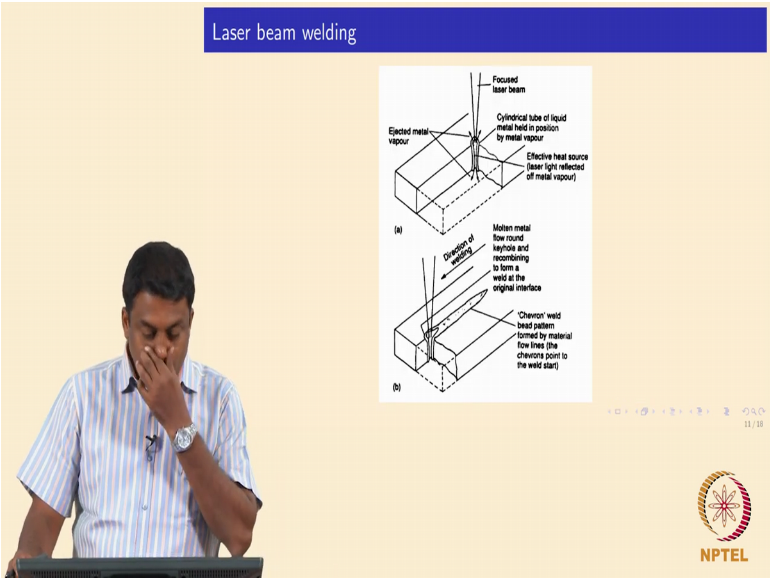

And if you look at in-depth how the keyhole is actually formed, so basically so when you have a laser actually it falls on the surface and we are welding along the directions, so this is your keyhole is formed. And keyhole is formed because of this severe heating of the molten pool leading to vaporization and then the temperature of the molten vapor of metal decreases as a function of depth right, so you end up vaporising more at the surface and then, so once you start vaporizing so you will end up forming holes because vapor is trying to escape right because vapour is trying to escape right so creating huge amount of vapour pressure. And this vapour pressure would try to push the expanding trying to the surface tension of the pool so it is better explained in yeah this way.

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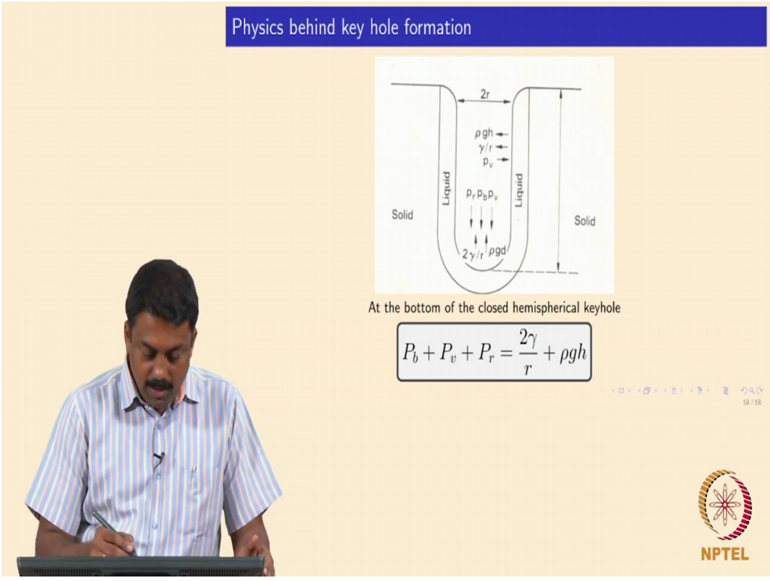

So when you look at the actual forces that have happened that are prevailing in the keyhole, the beam pressure the beam pressure is the pressure is actually coming from the kinetic energy of the beam itself okay, which would actually push the molten metal, so this beam pressure would always aid formation of the hole, is not it? Because that is the kinetic energy of the beam itself is like a plasma jet force right. And because of this kinetic energy dissipation you also vaporise, and this vapour would also try to push the liquid metal and that will also always create a whole right because of the vapour that are actually generated and this vapour is trying to push this around the liquid metal, it would always aid the hole formation ok.

And then when the vapours trying to escape from the hole, they also push they also generate the equivalent and opposite force like a rocket ok. So when the rocket when you send the hot gases it goes up, so when the hot vapours coming out of the hole, they will also create another force which would also always aid the keyhole opening ok that force is known as keyhole recoil pressure right. So recoil pressure is when they escaping jet of vapour coming from the hole and it also creates an equivalent force, a downward force that will aid opening of the keyhole ok. And these 3 forces would always aid the keyhole formation, the beam pressure is coming from the kinetic energy of the beam, the upper pressure coming from the accumulation of vapours, which would always push the walls of the keyhole.

And (())(23:07) force is recoil pressure, recoil pressure is generated when the vapour is escaping from the keyhole when you have equivalent force which is acting downwards which would always push the keyhole walls forming the keyhole. And there are other two forces which would try to close the keyhole which are gravitational forces right, so gravity so when you are welding the laser is on the surface okay so the gravity is also force will always try to close the keyhole ok. Then the surface tension of the liquid, it should also try to close the keyhole, is not it? Right.

So if you look at the force balance, if you want to have a stable keyhole which is extremely critical for laser welding, if you do not have stable keyhole, if the keyhole is collapsing and then expanding all the time and you also change the beige characteristics beige geometry, is not it? So if you do not have a stable keyhole and if it is expanding and contracting, your well shape is not uniform when you are doing welding right, so you will have more volume of material in metal molten we have a larger keyhole, and suddenly you will also reduce the well size to same size when the keyhole size is reduced okay.

If you have an expanding and closing keyhole, and you also change the well shape continuously during welding. And if keyhole is completely closed and then expanded and if it is exploded then you may also send a lot of liquid metal around and that is the pattern, is not it? So the force balance is extremely critical to get very good characteristics, so force balance in the stable keyhole is obviously the aiding forces should be equal to the closing forces, what are the aiding forces? The plasma, the beam pressure and then vapour pressure, recoil pressure, so B equal to the surface tension and the gravitational force okay.

Basically so if you have a liquid layer, and you will have this reforces which would always try to push the keyhole to close, which is gravity and the surface tension. Surface tension of liquid will try to close the bond, is not it? Similarly, gravity will also try to pull. Whereas, the vapour pressure would try to push because vapour is generated and it is trying to expand because of the hot temperature would try to open up the keyhole right. And then the recoil pressure when the vapour is escaping, it will also generate a downward force which will also try to open up the keyhole and the beam pressure which is actually kinetic energy of the beam which is actually always acting downwards, which should also aid the keyhole opening right, it is clear.

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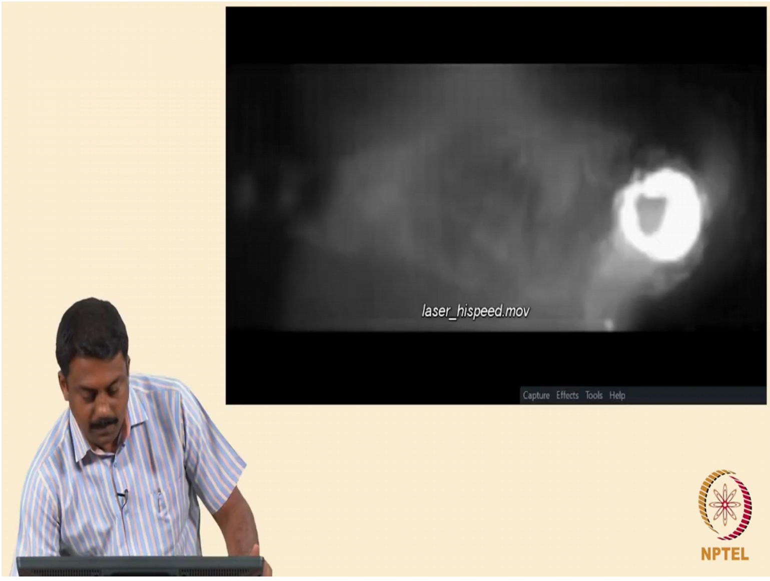

And these 2 forces should be balanced in order to have the stable keyhole, so the video I showed you, you see over here. If you see that the keyhole is not stable at all, is not it? So stable keyhole I would expect so it should have diameter of the top hole is constant when are welding continuously over a large distance ok. So there is a specific reason why we have in this case, or keyhole is opening up and then closing up and this kind of a keyhole behaviour it is not suitable for stable welding condition because in this case for example, if the keyhole is large, you have may have a large well seem more molten pool, so then the well width will be much higher ok and the vaporisation will also be very high.

And suddenly the keyhole is closing okay so that could lead to change in the well size as well as the closing of keyhole when it expands, subsequently it can also cause a lot of stirring in the molten pool and it may also expel the liquid metal to the other areas and causing a spatter ok. And we will see why it is happening and what is actually happening in terms of force balances which causes such behaviour in next class right ok good. Any equations so far? So we looked at the laser, so fundamentals of laser which is actually a (())(27:57) stuff, we can always refer what are the types of lasers right, so solid-state laser, gas laser and fibre-optic laser and diode laser we looked at, fundamentals and basic principles.

We also looked at typical laser welding setup right, and we also looked at the well pool and the keyhole behaviour in laser's perspective and why this keyhole stability is affected and what causes this stable keyhole formation and balancing forces we will see in next class right good.