Welding Processes
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Laser Welding Process – Introduction Part 01

So in the last class we were looking at resistant welding right, so we looked at all the variants of resistant welding. From resistant spot welding we have moved onto flash bud, resistance obstruct okay, projection welding, and then we also saw the capacitor discharge welding right. So now we move onto the next chapter, this chapter is on power beam processes. So what do you mean by power beam? So the beams which we actually use for a heat source, they are made aware optical rays in the laser or a beam, and we can also consider plasma is also power beam ok, plasma is also neutral state right, so plasma beam welding is also a power beam welding process where we can get a key hole mode of welding carried out because plasma itself it is a sort of state of metal right.

So we already looked at one of the power milling process which is plasma welding right, how we generate plasma, how we can get the keyhole welding by plasma. So in this unit we are going to look at true optical heat sources; one is laser, the other one is electron beam right. So before going to that again, now we will look at the introduction and physics of this process. We use very commonly laser for welding right. The 1st amplification is actually carried out on microwaves and then it was actually transferred to more mere infrared as well as the visible spectrum of optical rays.

When laser was invented, it was invented in Hughes lab ok and people made fun of this scientist who invented because what is the purpose of laser at that time so everyone thought that okay so this guy is doing some fancy experiments and then showing that how light can be made into coherent right so that is the property of laser right, coherency. What is coherency? Same wavelength okay that is monochromatic, is not it? Okay I mean when you say define coherency how do you define? Parallel… Yeah same phase difference ok so that is one point. What else will be the same? Phase difference will be the same, yeah phase difference same means amplitude will be the same.

Frequency okay, vibration frequency should also be the same ok, and then this both the wavelength wave path should also be the same ok. So then it becomes okay so that makes one of the laser properties okay which is high-power okay because of the… There is no phase difference between the waves, and all carry same frequencies okay the same wave pattern that is why it is called coherent. So the moment we make beams highly coherent ok and then the light should also be not diverging, is no it, because if it diverges then it loses its property, it should also be collimated, is not it? So when you take a laser pointer and point it on the wall, diameter remains the same more or less, very small divergences if you convey a laser pointer right so that means that they do not divert okay, it is collimated beam.

And these properties make laser very attractive, when it was invented no one thought okay laser can be used for something, but now we cannot imagine life without laser right, we use laser almost every day for some other purpose or some purpose because we are looking at display something is reading we all right, is not it? Laser is used to read the data, so use it for welding but different power ok, and for biological applications lasers are used for various you know noble laureates use laser for various bio applications, they made suitable lasers for bio applications that is why he got Nobel Prize ok.

So without laser we cannot imagine life but it was invented no one ever thought okay what is the use of laser ok, so it is one of the classical examples of academic research is that we always say about the laser and scientists work done to generate laser, I mean the research does not have immediate use but 10 years by the time in 1970s the laser started you know in commercial applications when the semiconductor industry started growing, alright ok good. So this is a history when laser was invented in 1960, then the welding, the use of laser for welding already started in 1980s or so ok because the capacity of laser (())(5:55) ok because for welding applications we need to generate large amount of power ok.

For biological tissue applications engineering we need few watts, whereas in welding we need a few hundred watts ok, so if you want to weld a 2MM thick in the keyhole mode you need at least 1 kilowatt 1000 watt ok, so but we can generate lasers in various ways right, so you must have studied in physics right so we will look at some of the introductions in this class and then we will move on to laser welding system right.

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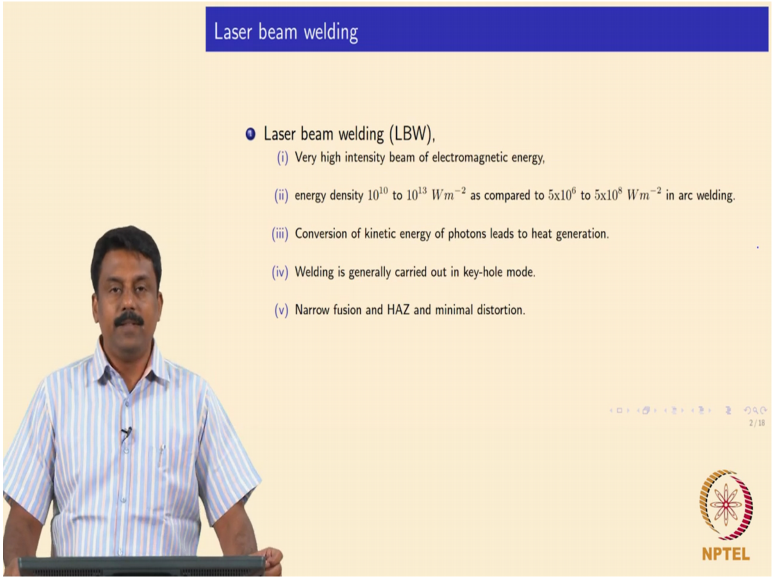

So why what is so special about laser welding? We will use very high intensity electromagnetic energy ok that is why laser, so laser is very coherent and you can manipulate the laser beam very easily okay this is an optical ray, it can be transported from one place to another place using a proper optical setup. Nowadays we use Fibers to transport laser from one point to another point, so transport laser from one point to another point and we can be manipulating the lasers very easily ok so we can also access the laser in very short corners or geometrically difficult positions where as in the conventional arc welding setup we need to have some geometrical limitations whereas in the laser we can manipulate the beam very easily right.

And because of the highly collimated coherent beam we can achieve extremely very high-density energy density in a very narrow region right, so if you have and I have work done even 20 kilowatt laser where the laser spot size is less than a millimeter. 20 kilowatt of power is focused on 800 microns beam ok, so such a high-power can be concentrated onto a very tiny area, so the energy density can be very high okay. For example, in fibre-optic laser the energy density can go as high as 10 power 10 to 10 power 13 watts per square meter ok 10 power 10 watts, it is a huge amount of energy can be focused on a very tiny area.

Okay, whereas in arc welding case it is almost half of that that is why laser can be used in fact the electron beam also can be made into such high energy density process right. And how do we generate heat? Because these photons laser photons, they have a kinetic energy ok, when the kinetic energy is transferred to a work piece metal when the energy is converted into thermal energy because these photons when it actually impinge on the sample, they get attenuated ok so they interacted with the base material. And due to this process the Kinetic energy of photon are converted into thermal energy ok, we will see in the subsequent clauses the energy balance again in the physics so that is the main heat source is laser photons and the Kinetic energy of these photons are converted into thermal energy which is actually used to melt and then fuse the interfaces ok.

In most of the cases because of the very high energy density welding is carried out in keyhole mode, so we looked at already in the plasma welding right keyhole. So through thickness hole we make the shape of keyhole and because of that we can achieve very high penetration ok, and because the energy is concentrated in a very tiny area so we can also achieve very narrow (())(10:09) and because of the steep thermal variant, the distortion can also be minimized significantly okay, these are some of the characteristics of laser. In most of the cases because of very high-density of laser beam we do not use any extra filler ok because we can melt enough to fuse the interface, so most of the cases laser welding is done in autogenously mode that means we do not use any extra filler.

Okay so we can use laser as such, we can melt the entire interface, we can form keyhole and then the interface can be welded. Yes it is clear right, so this point is very attractive so this can be increased to several times higher nowadays, thanks to the invention of fibre lasers ok the limitation in the laser source is now reduced significant because we invented a new way of creating lasers using optical fibres okay, so optical fibres can generate laser as high as I have seen in one of the labs in Japan, the laser power can go up to 100 kilowatts ok. So 100 kilowatts is a huge amount of power whereas, we are going to buy in IT in our lab as well in the end of this year, 4 kilowatt laser ok.

So 4 kilowatt is good enough to have a full penetration of 8MM thick steel ok, so 8 MM thick steel can penetrate, imagine if we have 100 kilowatt laser so about half a meter we can melt easily, so such high-power lasers are used even for welding applications to weld some of the structures used for nuclear applications because we may have to weld the last thickness which should not damage the work piece severely so that you know we minimise the (())(12:26) in distortion control. So these kinds of applications where we need highly energy density laser is very ideal because it also gives us very narrow wave zone and fusion zone. Sometimes this is not acceptable, so when we have very narrow wave zone obviously you also have very narrow stress concentration area, is not it? The cooling rate of this process is much higher laser welding, so you invariably end up getting a multicity microstructure.

So if you have a very narrow well zone bulk structure and that zone is the actually stress riser ok, so you end up partitioning it was a very narrow region so in that case sometimes it is not advisable to have narrow (())(13:15) then the structure is extremely loader. Whereas if you just want to meet a joint weld joint, the loading is not that severe then the laser welding is very nicely used in those kinds of applications ok, let us move on.

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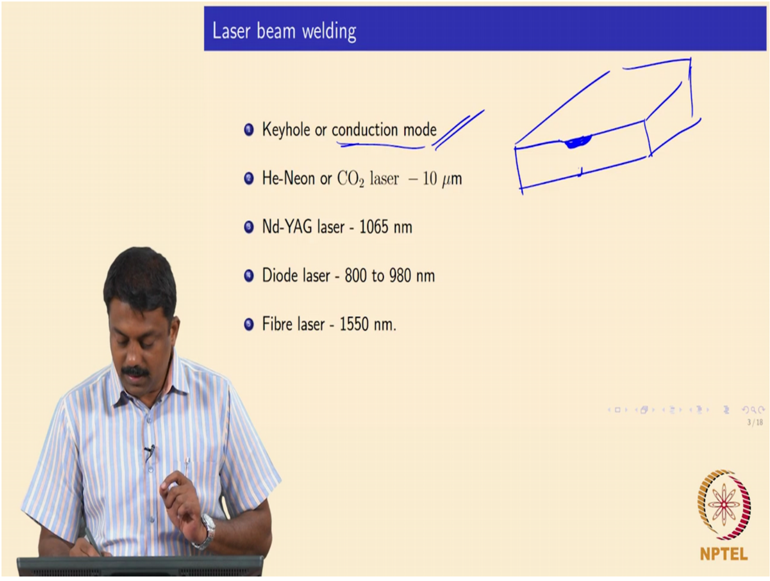

So what are the types of lasers we can have? So in the welding general is carried out in a keyhole mode or conduction mode, so what do you mean by keyhole and conduction mode? I have already explained it to you in plasma welding, right. So keyhole mode is so you will have suppose this is your material, say laser is actually impinge on the sample (())(14:01) the moment there is interaction happen if laser power is high enough, so you may end up penetrating like this ok. So the shape of the laser penetration is like a keyhole okay. So if the power is high enough, you will have a through thickness keyhole and you will have metal vapour which is actually causing the very strong generation, so we look at the force bagons in the keyhole in later lectures

But now we can imagine that if the power is high enough you can have a full penetration with the keyhole or you can also reduce the power or defocus the laser both ways so that you do not melt the entire cross-section, you just melt the surface ok so let this area is involved in it. So this type of melting is not as doing welding in conduction mode, and this is done not to melt the entire cross-section for various reasons. For example, you just know you want an alloy or you want to change the surface condition ok we want deposit a powder onto a surface like a cladding. So in that case you do not need to melt the cross-section, so you use very low-power laser or defocused laser and then you melt powder on top surface, the laser can be used in conduction mode in that application so that you do not melt the entire cross-section, you will just melt only the top surface, right.

And based on the laser source we can also classify the laser types; gas laser, solid-state laser and diode laser or fibre laser ok. So this you must have studied already in school days right, so the most commonly used is the gas laser or helium neon or carbon dioxide laser. And what do these gas do? So what is the purpose of having these classifying this gas solid state fibre? So these are lasing medium okay, when you excite an atom obviously the electrons in the ground state would be excited to an excited state right. So when these excited state electrons goes back to its ground state, the excited energy is released by emitting a photon ok and this bandwidth determines the wavelength of the photon, is not it?

So the bandwidth determines the wavelength of the photon, so this lasing medium the exciting medium neither can be gas or solid or even fibre. So if you use gas so obviously the wavelength will be determined by the band gap is not it? The energy gap between the ground state and the excited state, so that determines the wavelength. For example, helium neon and CO2 laser would generate a wavelength of 10 microns, the laser with 10 microns wavelength ok. And you can also use solid-state laser so most commonly used laser source is Nd-YAG what is Nd-YAG? What does Nd stands for? Yeah so Neodymium and YAG yttrium aluminium gallium, what G stands for? So it is yttrium aluminium garnet ok, so yttrium aluminium garnet and that can be used as a lasing medium, right.

And yttrium aluminium garnet Nd-YAG is doped with neodymium ok so that is solid, YAG is generally doped with neodymium atoms so then it becomes a very stable laser medium otherwise, when you do not do with neodymium the stability of the laser source goes down because once it excites, it also loses its life okay so that is why we dope with neodymium to increase the shelf life ok, so that we can the solid-state laser source can serve for a long time. So when you use Nd-YAG, the wavelength of the Nd-YAG the laser is 1065 nanometre.

And of course you can use various diodes, so diode can also generate lasers so diode lasers the wavelength can be varied from 800 to 980 nanometre, and nowadays we use optical fibres okay so even in optical fibres the very latest development is we use graphene graphene mirrors in optical fibres to generate very high efficiency lasers with power going up to 100 kilowatts okay. And because the entire laser principle works based on the excitation of the electrons, the life of this laser source is limited except the fibre lasers, fibre lasers they work in different principles than the gas solid-state lasers. So if you use a solid-state laser, over the time you also lose the efficiency significantly right because the efficiency determined by the energy difference between the input to the output right.

So over the time and the gas source actually it is the solid state laser source they loses the efficiency because the moment you excite and then de-excite the electrons and the material also degrades over time ok. So solid-state laser, the laser rod you will have to replace after 5 years or so, otherwise initially it may generate 4 kilowatts, after 5 years you will never reach 4 kilowatts because of the (())(20:57) of the cyrstals, so it will end up losing the output power so after 5 years you know getting 2 kilowatt in a 4 kilowatts system itself is very challenging. Same goes with diodes as well, diode also degrades over time in the excitation cycles so we will have to change the diodes ok. So we will see one by one some of the basic principles, mainly fibre laser we will consider and because the gas solid-state laser so they are actually going to go away in previous time so we will now move onto the fibre lasers.

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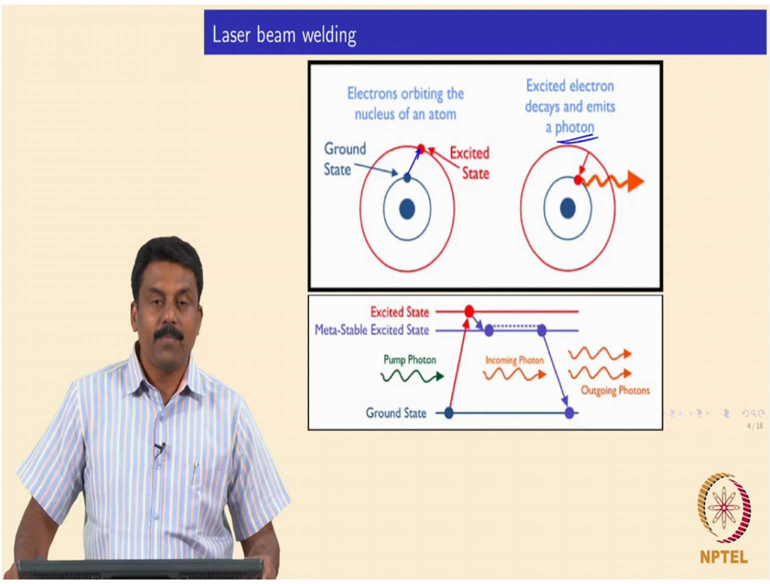

Ok so the basic principle is the same for all ok, so when the electrons orbit in its own orbit, there will not be any (())(21:46) so we send some energy to excite the electrons, the moment the electrons are excited so they are in higher energy state, is not it? And then when you release the energy the exciting energy, the electrons will come back to its own state. And during this process whatever energy is observed by these excited electrons is released in various forms, one of the forms is photons. And you also get it (())(22:15) various things but you may also get a photon released and then these photons when released that can be made into highly coherent by using special arrangements okay, you need to have some reflective mirrors and these mirrors can make these photons to high energy laser by increasing the frequency as well as by making them into same path difference ok and then becomes coherent.

And once they become coherent and gain in power and they can be released through partially reflective mirrors and that is what you use it as laser, is not it? So the main purpose the main idea behind this process is to so we give some energy which is known as pumping energy or pump photon ok so pumping energy can be given by another laser itself okay, so you may also use the laser itself, a small laser as a pumping laser to excite the electrons in the gas medium or solid-state medium. And then moment these are excited and then you will have avalanche of excitation leading to photon generation. So these excitations can be brought into ground state the moment you switch off the pump energy ok, so it is very simple right, so this is the basic principle of the photon emission.

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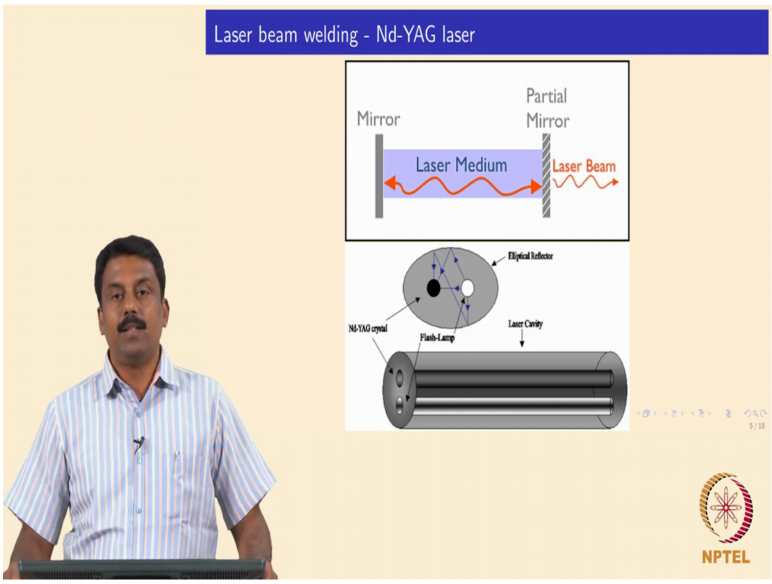

And because we are stimulating this photo animation ok so that is why the laser comes from. And then the stimulated photon emissions are amplified using a suitable mirror assembly, is not it? Stimulated photons for amplified by having a medium in which these simulated photons are sent they are confirmed, is not it? And during this process they get collimated okay they are made into coherent and they are amplified into a very high-power, the moment you achieve a perfect collimation as well as coherency and they can be made into go out using a partial mirror and this mirror has a special reflective coating and which can only send a coherent beam, right that is how the (())(24:53) medium works, right. And this laser medium can be gas, can be solid-state, okay can also be a diode right.

The principle is the same, say for example, this is the gas source say CO2, helium neon gas mixture or you may also have Nd-YAG rods ok Nd-YAG rod containing partial and fully reflective mirrors same principle okay. So you will have a pump photon, pump energy or pump laser which would excite the Nd-YAG crystals and doing this process so the (())(25:36) can lead to generation photons, the moment photon are generated ok and they can be amplified using the mirrors and then collimated and including power, and using partially reflective mirrors these photons can be sent to beam delivery right, so this is a very simple mechanism of laser generation right ok.

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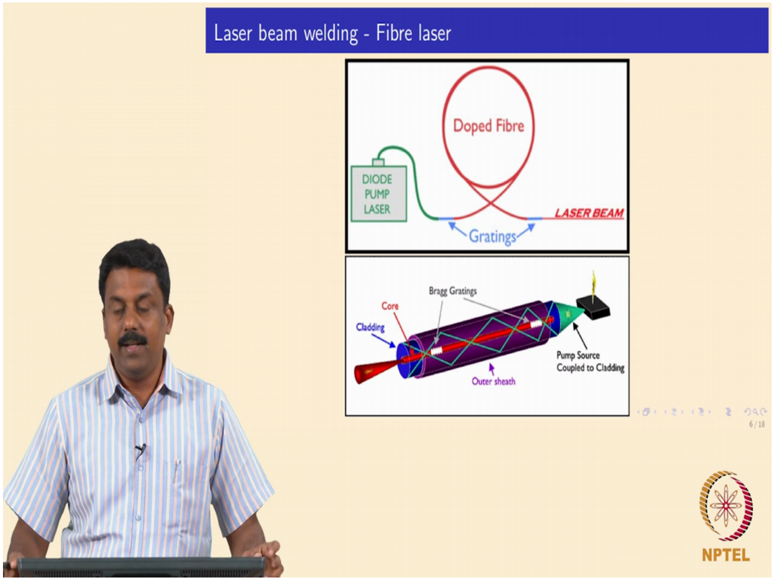

So in fibre laser things are slightly different, in this case we do not use any medium so we use fibre-optics the fibres as a lasing medium ok, so we send a pump source to clad optical fibres and this source or accelerator and then amplified and then coherent and then collimated using the reflective surfaces of these optical fibres right. So the moment they are collimated and made into coherent and they can be send into another optical delivery system and which can send the lasers to the workstation right. So most of the cases the pump source is using diode lasers, and these diode lasers sends the primary pumping laser source and that source is send to the optical fibres which are reflective surfaces, which are actually doped with highly reflective mirrors mostly like gold surface.

So most of the cases copper coated with gold that is commonly used as reflecting surface in doped fibre optical cables, and then the moment it becomes coherent and collimated can be sent into beam delivery system. The advantage of this fibre-optic system is the laser source is very flexible, is not it? It is a fibre ok, so fibre is very expensive by the way, so 1 meter costs about 20 lakhs or so ok so it is very expensive. So you get a fibre of 5 meter for a crore right, the longer the fibre, the more will be the beam coherency and the (())(28:08) the high-power obviously, so for 4 kilowatts you spend about 5 crore to get a fibre laser. So you can get the fibre and it is very flexible right, so you can also manipulate and you can send the (())(28:24) somewhere else and then get it delivered.

For Nd-YAG system so the Nd-YAG is very huge ok so if you look at the 4 kilowatt Nd-YAG, you need each Nd-YAG crystals can be made into 200 watts and it also needs a pumping source, the pumping source can be laser or another lamp, diode laser can be. So if you have a 4 kilowatt Nd-YAG system so it will be of this room size laser source right, whereas in fibre it can be like a small tabletop ok, it can beam generating the same amount of power what it generates with the huge system and the efficiency can be very high in the optical fibre system because in Nd-YAG system, the pumping energy what you send is not all energy is converted into laser energy so efficiency is not even 5 percent laser efficiency ok.

Any questions so far, how we make how we use laser? Right so it is very simple so it is not there is no complex. And we do not spend much time in the laser production because we assume that you know laser is produced and then we can use it for welding right.