Advanced Machining Processes

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Module - 08
Lecture - 18
Laser Beam Machining (LBM)

Welcome to the course on advanced machining process. Today we shall discuss about a new process which is called laser beam machining process. So all of us are familiar with the important experiment we have done during our childhood when a sunrays or sunlight is focused into a small area of a piece of paper by using a lens. So when this sunlight is focused on a very small piece of paper by using a lens energy density of 1 watt power mm square is generated. So this energy is sufficient enough to burn the piece of paper.

Similarly huge amount of energy can be generated in laser also by focusing this laser light into a very small area so that we can get a high energy density and we can do the different kinds of operation like cutting, drilling, machining, micromachining, trepanning, so different kinds of operations we can do and more as this laser light is concentrated into a very small area a very small hole can be made by using this laser beam machining process. So hole diameter, high aspect ratio hole with a hole diameter less than 1 mm can be produced by using this laser beam machining process.

So first we shall discuss the working principle of this laser beam machining, how this lasers are generated. After that we shall discuss this different kinds of lasers, solid state laser, gas lasers. After that we shall discuss the process characteristics of laser beam machining process and at the end we shall discuss the different applications of laser beam machining process. So first we shall start the working principle of this laser, how this laser is generated.

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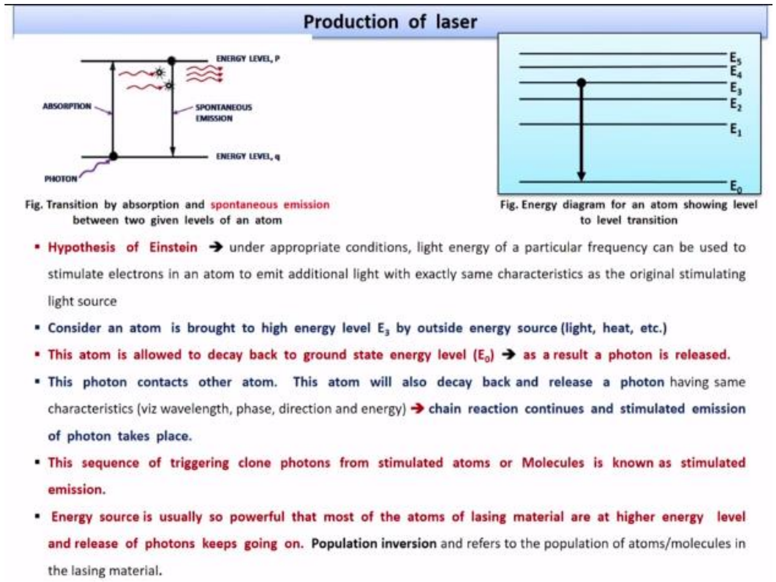

So Einstein hypothesized that under appropriate condition light energy of a particular frequency can be used to stimulate the electrons in an atom to emit additional light with exactly same characteristics as that of the original stimulating light source. So consider this figure here, an atom, so when in this figure so when this atom is in Q energy level and light of a photon is falling on this atom so this atom actually this photon is absorbed by this atom.

Now this atom comes to higher energy level at P. So this atom cannot stay at this energy level for a longer time so it will decay back to the lower energy level. So while it is coming back to its lower energy level so it will emit a proton. So there are 2 types of emissions are there. One is stimulated emission and another one is the spontaneous emission. Stimulated emission is there so this emission actually does not depends on the stimulated light.

It is independent of the in stimulated emission it is dependent on the stimulating light source or heat source so then it is called the stimulated emission and spontaneous emission it is independent of the stimulating light or heat source so then it is called the spontaneous emission. So there are 2 operations are going on, one is absorption of photon by an atom, it comes to an higher energy level and then it comes or it decays back to its lower energy level. While it is coming from the higher energy level to the lower energy level it emits a photon. So this emission is either spontaneous emission or stimulated emission.

So 2 types of emissions are there. So consider an atom in the second figure, is brought to a E3 by an outside energy source like light or heat. So this atom is allowed to decay back to the ground state at E0. So as a result photon is released. This photon contacts with other atom in that lasing medium so this atom will also decay back and releases a photon having the same characteristics means same wave wavelength, same phase, and same direction, and same energy. So it will also generate another photon having same characteristics like same wavelength, same phase, same direction, and same energy. So this chain of reaction actually continues and stimulated emission of photon takes place. So this sequence of triggering of clone photon from stimulated atoms or molecules is known as the stimulated emission.

So energy source is usually so powerful that it is required to be so powerful that most of the elements most of the atoms in the lasing medium should be higher energy level and it will release and releases the photon and release of the photons keeps on going on okay. So this is called actually population inversion and refers to the population of atoms or molecules in the lasing medium.

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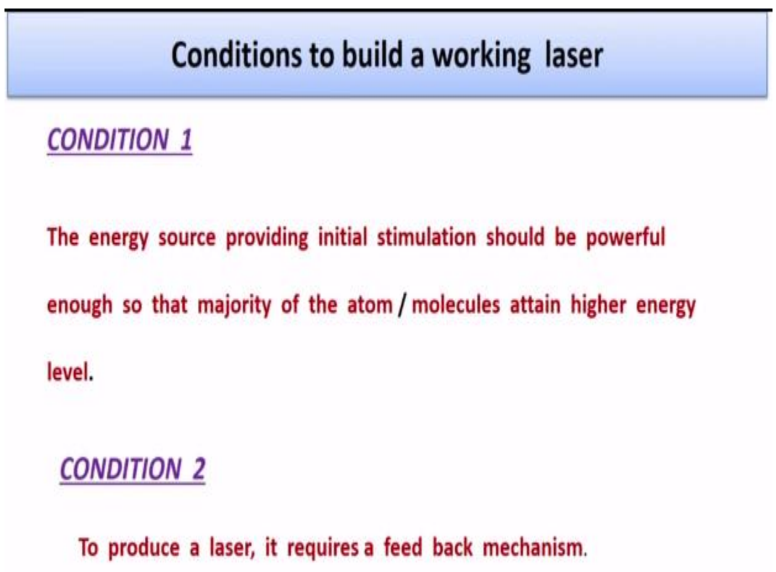

So now for this stimulated emission of this photons or laser, there are 2 conditions which has to be fulfilled. So for a working laser there are 3 conditions, there are 2 conditions which has to be fulfilled. So first one is the energy source providing initial stimulation should be powerful enough so that majority of the atom and molecule in the lasing medium should be in the higher energy state. If majority of the atoms are not in the higher energy state, so it will not generate the photos while it is coming digging back so it will not generate the photon.

So most of the atoms in the lasing medium should be at the higher energy level. So you need an external source like heat or light so that most of the atoms can be in the higher energy level. Now condition 2 is that to produce a working laser it needs a feedback mechanism. So this feedback mechanism we shall discuss in a later slides.

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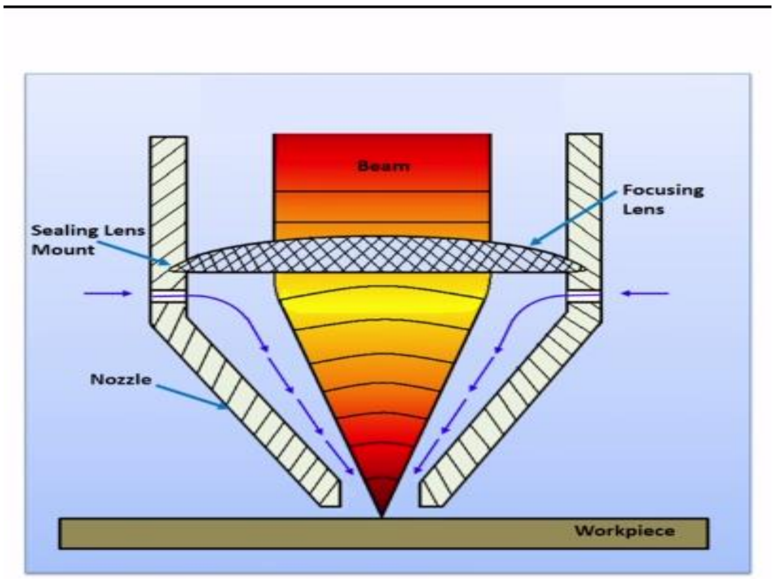

So now you can see here this is the laser beam, so series of photons are coming from the lasing medium from higher energy level to the lower energy level. So this photons are generated. So this photons or lasing medium, this photons are actually focussed by using a simple lens, so it is focussed by using a simple lens.

So while it is focussing so it can concentrate you can see here, it can concentrate into a very small diameter, so it is less than 1 mm so it can be concentrated into a very small diameter so these amount of energy, high energy density can be achieved by using this laser. So this amount of energy can be used for melting and for localised melting and vaporization of the material. So here you can see here this is the assisted assisting gas is there. So this assisting gas actually helps to cool down the material. Also it helps to eject the molten or vaporized material from the machined surface. Also it helps to avoid this molten material to damage the lens.

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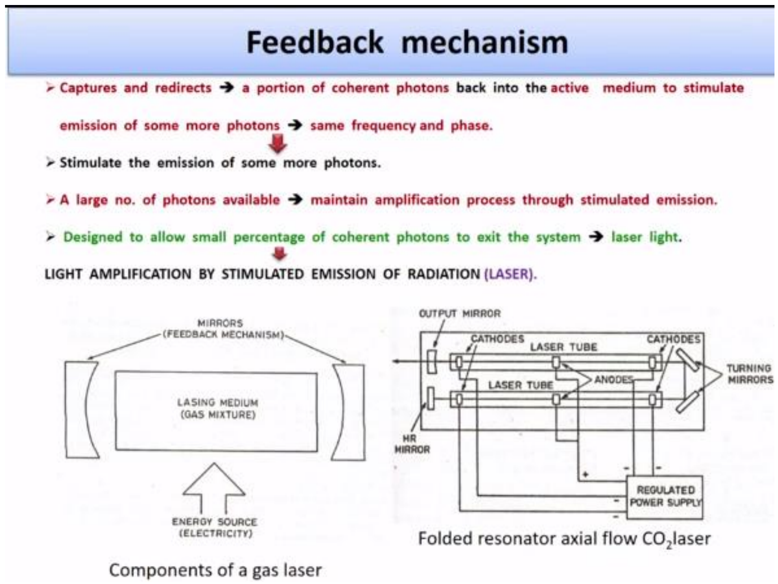

So what is feedback mechanism, feedback mechanism so this photons actually generated during laser in the lasing medium so for machining to take place actually we need a sufficient amount of photons. So when there is a beam of photons, beam of energy is actually falling on a workpiece surface then only there is a machining. So you can use this laser for the machining to carry out. So to generate more number of photons there is a feedback mechanism is required.

So this feedback mechanism is that it captures and redirects a portion of the coherent photons back into the active lasing medium to stimulate emission of more photons so that same frequency and phase of this photons can be generated. So whatever photons are coming outside from this lasing medium it reflects back it captures and redirects the photons into this lasing medium again so that it stimulates the more atoms of this lasing medium so that emission of some more photons can be generated, some more photons of same frequency and phase can be generated.

So it basically stimulates the emission of some more photons into this lasing medium. So as it emits more number of photons into this lasing medium so a large number of photons are available for this machining so it maintains the amplification process through the stimulated emission, so it maintains the amplification process through this stimulated emission.

So it is designed to allow the some percentage of this coherent photon to exit the system as a laser light which is used for the machining purpose. So what is the full form of this laser, laser is light amplification of stimulated emission of radiation. So you can see here this is the lasing medium here. So there are this is the feedback mechanism which is used so now this is the heat source or light source or energy which is used to stimulate the atoms in the lasing medium to a higher energy state so because of this feedback mechanism this whatever this photons which are coming outside it is redirected into this lasing medium again so that it can reacts with the more photons generates emission of it helps to generate emission of more photons. So this feedback mirrors. So these are feedback mechanism, it is nothing but are mirrors. So photons are actually reflected back from this mirror and come again into this lasing medium. So this full form of this laser is light amplification of stimulated emission of radiation.

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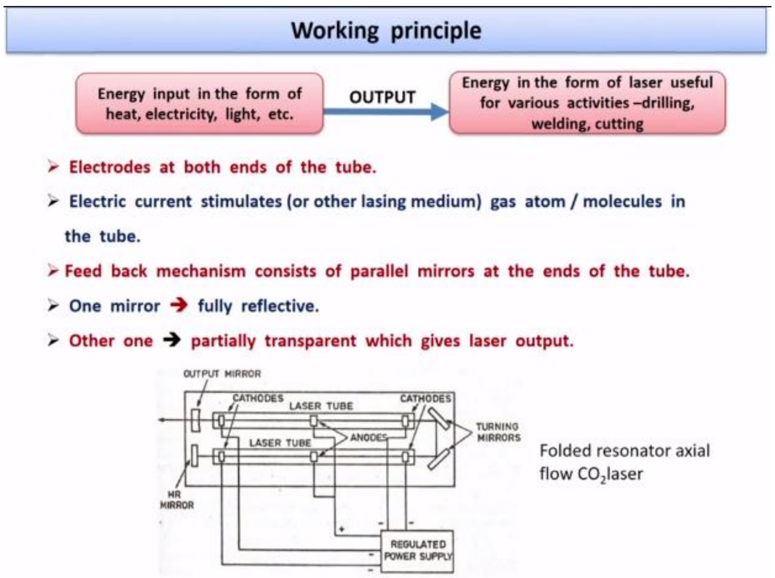

So now what is the working principle of this laser. So energy input in the form of heat, electricity, or light is given into this lasing medium as a source of energy to stimulate the atoms to a higher energy level. So now this energy from this laser medium come outside as a laser wave which is useful for different activities, machining activities like drilling, welding, cutting, soldering, heat treatment, hardening of workpiece material and many things.

So electrodes are actually used at the both end of the tube so you can see here so this is the gas laser here. So here you can see this is the cathode and this is the anode here, again there is a cathode is there. So this is one tube which is filled up with the gas maybe CO2 gas, carbon monoxide gas, or helium gas or nitrogen gas as a lasing gas it is filled up at a low pressure. So 2 electrodes are actually used to energize the atoms and molecules of this gas to release the photon. So this electrodes are used at the both ends of this tube.

Electric current stimulates or in maybe other lasing medium other lasing medium stimulates the gas atoms or molecules in the tube. So feedback mechanism consist of a parallel mirrors at the end of the tube. So one mirror is fully reflective and another mirror is partially transparent which gives the laser output. So here you can see this output mirror which is partially transparent. So through this partially transparent mirror lasing this photons actually come outside as a lasing medium as a laser photons come outside but this mirror and this mirror these are actually highly reflective mirrors. So this is highly reflecting mirrors. These are the turning mirrors.

So these are the 2 pipes are there. So when photons are actually coming outside from this pipe it will be reflected here then again it will reflect here in this mirror and then it will come inside of this first chamber and it may transmit through this partially transparent mirror but here this highly reflecting mirror when this photon is coming outside from this highly reflecting mirror because of this highly reflecting mirror so it will come inside after reflection from this highly reflective mirror. So again it is coming inside okay.

So here this is it redirects the photons to come back again into the lasing medium. So for this CO_2 laser or gas laser this kind of folded resonator axial flow CO_2 laser, it is a folded resonator axial flow axial flow CO_2 laser okay so this for generating 100 watt of laser power certain length of the gas is required. So when we need a huge power, we need a longer pipe. So this longer, very long pipe we cannot make inside a lab. So this kind of small small pipes we can keep so from every pipe so this kind of turning mirrors can be used. So this photons after getting outside when it comes outside it is reflected by using this turning mirror to the lasing medium again.

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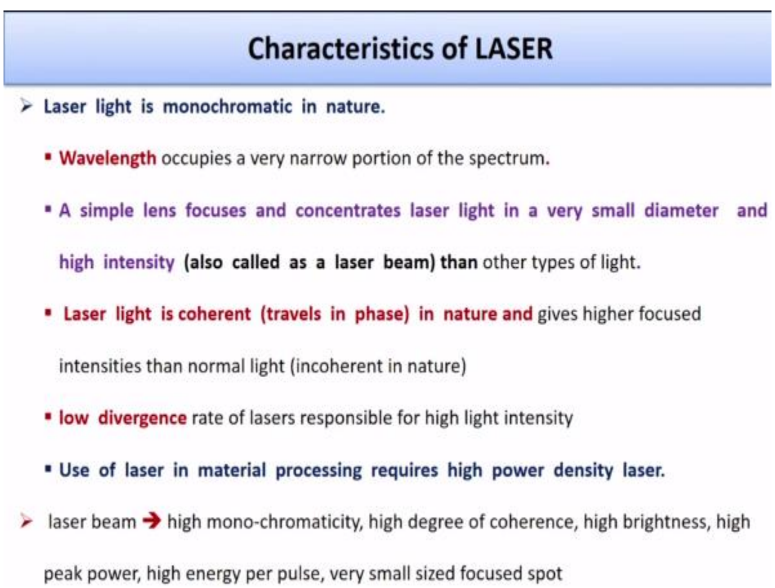

So laser light is so what are the different characteristics of the laser light. So laser light is monochromatic. Monochromatic means its wavelength occupies a very small region, narrow portion of the spectrum. So that is why it is called monochromatic. So because its wavelength occupies at a small or narrow portion of the spectrum so that is why laser light can be focused into a very small area because its wavelength lies into a very small narrow region.

So a simple lens can be used to focus and concentrate this laser light into a very small area or small diameter and because of this high intensity laser beam can be generated so which is not possible by other type of lights. So because of this monochromatic property it concentrate it can be concentrated using a very simple lens into a smaller area so that is why high energy beam can be generated which is not possible by other kind of light.

So light laser light is coherent so it travels in phase. So coherent in nature and gives higher focused intensities than normal light. So normal sunlight which is not coherent which is highly incoherent. So as the laser light is coherent it is travels in phase. It can give highly focused intensities. Also laser light has high means low degree of divergence. Divergence means deflection of the beam per unit length traverse of the laser light. So it has a very low divergence rate, laser light has a very low divergent rate so which is responsible for the high light intensity. So that is why use of laser in material processing requires high power density laser.

So laser beam having degree of mono-chromaticity, high degree of coherence, high brightness, high peak power, high energy per pulse and very small size of the focused spot are responsible for machining for cutting, drilling, welding, for hardening, for heat treatment of this of the material. So these are the properties which are responsible for using in different machining operations.

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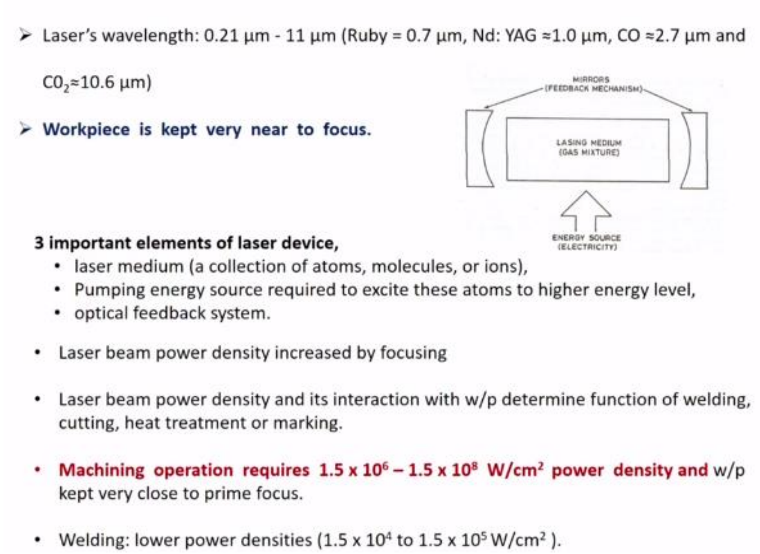

So laser lights wavelength varies in between 0.21 micron to 11 micron in between ruby as very small 0.7 micron Nd YAG laser it has a 1 micron wavelength and CO carbon monoxide it has 2.7 micron and CO2 it has a 10.6 micron wavelength. So to use the laser for this machining of workpiece so workpiece should be kept very closer to the focal point of the laser. So there are 3 different elements of the laser device. First one is the laser medium.

So here laser medium, a collection of atoms or molecules or ions which generates the photons and second element is the pumping energy or heat source required to excite these atoms into a higher energy level and the optical feedback system which is used to regenerate this photons into the lasing medium again. So laser beam power density can be increased by focusing. So by focusing, by using a lens this laser beam power density can be increased.

So laser beam power density and its interaction with the workpiece determine function of welding, cutting, heat treatment or marking. So different kinds of operations can be done based on the energy density. So high energy density is required for machining operation so maybe 1.5 into 10 to the power 6 to 1.5 into 10 to the power 8 W/cm square.

So this much of energy is required for machining operation and workpiece also is kept very close to the focal point and low energy density can be used for welding purpose so maybe this laser beam power source laser beam density can be in the range of 1.5 into 10 the power 4 to 1.5 into 10 to the power 5 W/cm square which is lesser than energy lesser than for cutting operation.

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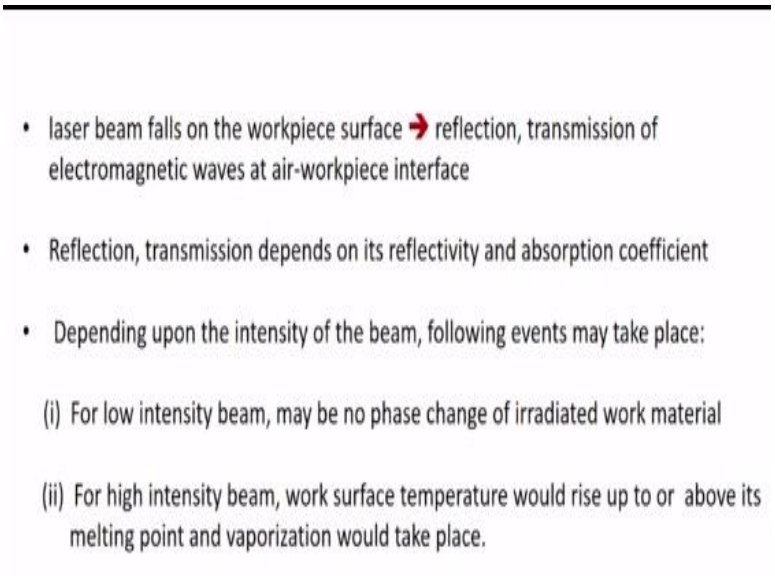

So laser beam falls on the workpiece surface so there are different phenomena occurs. Some of the light, laser light may be reflected on the workpiece surface. This may be transmitted into the workpiece surface. So transmission of this electromagnet waves at the air-workpiece interspace so many things can happen. So reflection and transmission of this laser light depends on the reflectivity coefficient and transmission coefficient of this or absorption coefficient of the workpiece material. So depending on the intensity of this beam one of the this phenomenas will occur.

When this laser beam power density is low so in that case no phase change of this workpiece material may happen. So there is no phase change of this workpiece material so there is no machining may happen and if this laser beam power density is very high workpiece surface surface temperature may rise beyond the melting or boiling temperature and then it that case vaporization of the workpiece material where laser falls may happen and machining may carry on.

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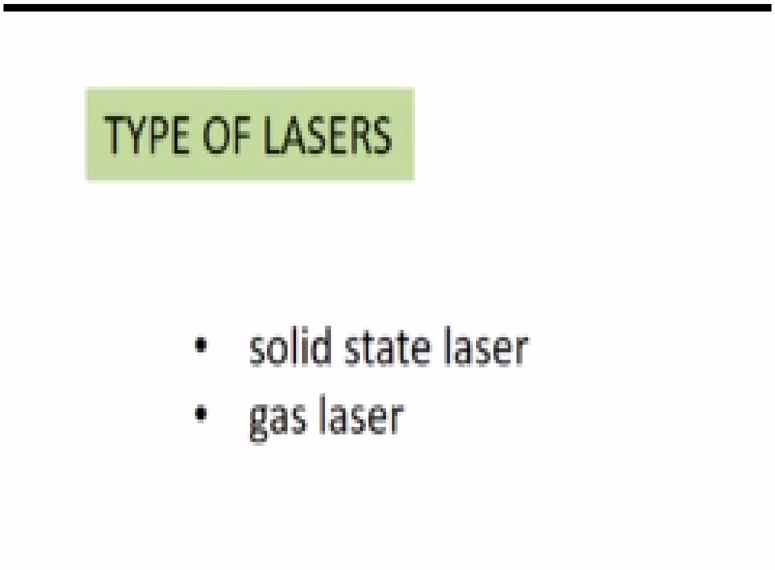

So there are different types of lasers are there like solid state laser or gas lasers, either solid state lasers are there or gas lasers are there. So first we shall discuss different kinds of solid state laser.

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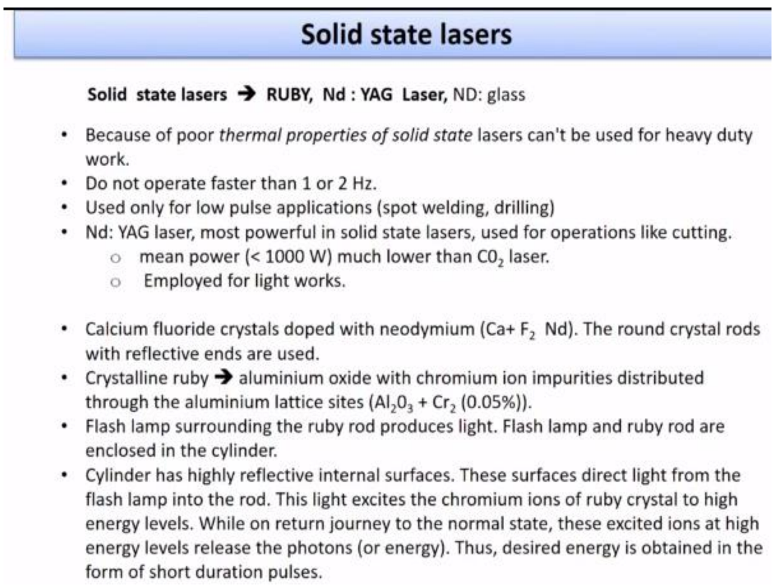

So solid state laser like ruby, Nd YAG laser, ND glass laser these are the various kinds of solid state laser. So because of this poor thermal properties of this solid state laser this lasers cannot be used for heavy duty application. So this kind of lasers will heat up so it has a poor thermal properties. So it cannot be used for heavy duty operation. So also this kind of laser, solid state lasers does not operate faster than 1 to 2 Hz. So it does not occur at faster than 1 to 2 Hz.

So used only for low pulse application like spot welding or drilling operation where low pulse are required so this kind of low pulse application because it has a its frequency is less than 1 to 2

Hz. So Nd YAG laser most powerful in solid state lasers used for operations like cutting. So its mean power is less than 1000 W but which is much more than this CO2 laser but its energy density is very high. So it is employed for this light works.

Calcium fluoride crystals doped with neodymium, so this calcium fluoride when it is doped with neodymium so this round crystal rods with reflective ends are used for the generation of the photon like in crystal and ruby aluminium it is nothing but the aluminium oxide with chromium as the doping material or impurities material so which is distributed through the aluminium lattice sites.

So this chromium it consist of 0.05% into this aluminium oxide. So one flash lamp is actually used surrounding this ruby crystal or ruby rod which produces this light and this flash lamp along with this ruby crystal ruby rod is kept inside a cylinder. In that cylinder that internal surface of the cylinder is highly reflective. So lights from the flash lamp it reflects from the internal surface of this cylinder it falls on the ruby crystal or ruby rod which is enclosed inside the cylinder.

So these surfaces direct the light from the flash lamp into the rod so this light actually excites the chromium ions of this ruby crystal to higher energy levels. So while on return journey to the normal state, to the ground state this excited ions actually at the high energy level release the photons or energy. So this desired energy is obtained in the form of short duration pulses.

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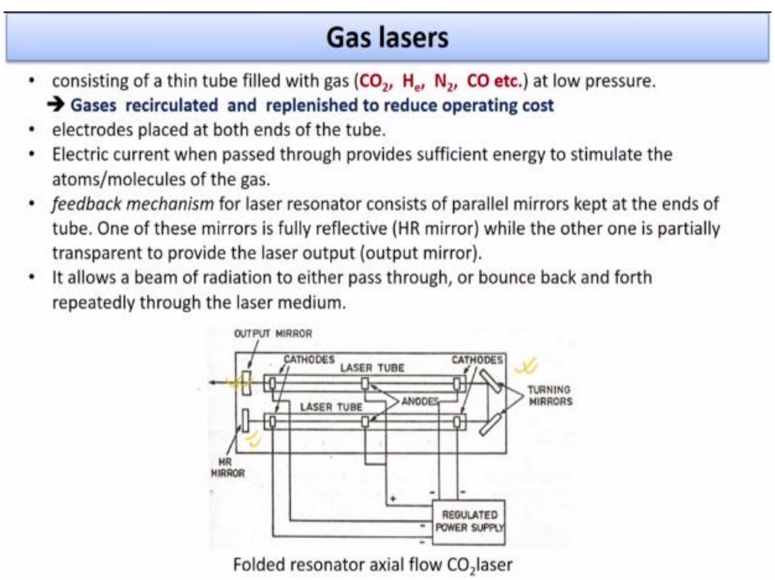

So now this gas laser, so gas laser already I told. So this is the configuration of a CO2 laser. So it is a consisting of a thin tube filled with carbon dioxide, nitrogen, helium, or carbon monoxide at low pressure so this gases are recirculated and replenished to reduce the operating cost. So electrodes are placed at both ends of the tube and electric current when passed through the tube provides the sufficient energy to stimulate the atoms or molecules of the gas.

So now feedback mechanism you can see here. Feedback mechanism is applied for laser resonator consist of parallel mirrors kept at the ends of the tube. One of this mirror is fully reflective mirror, highly reflective mirror, so this one is highly reflective mirror while the other one is the partially transparent to provide the laser output.

So this is the partially transparent mirror. So it allows the beam of radiation to either pass through or bounce back and forth repeatedly through the laser medium. So it is partially transparent and few beams actually it is bounced back or returned back into this laser medium and high energy beam are actually come outside of this partially transparent mirror as a laser light.

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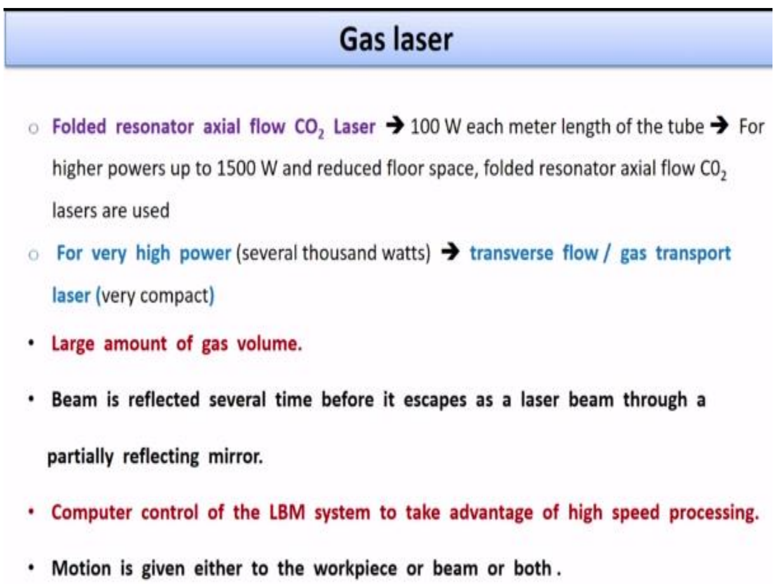

So folded resonator axial flow CO2 lasers are used. So maximum 100 W laser power can be generated for 1 meter length of the tube. So suppose our requirement is a few kilowatt so in that case the length of the tube will be very high, very long so you can use a small length of the tube and many tubes you can connect together so in that case folded resonator axial flow CO2 lasers are used to reduce the floor space.

So for very high power, several thousands of watts, so transverse flow gas transport laser which is very compact is used. So large amount of gas volume is required. So beam is reflected several times before it escapes as the beam laser beam through a partially reflecting mirror. So computer control of the laser beam system is used to take advantage of the high speed processing. So motion is can be given either into the workpiece or either into the workpiece or it can be given to the laser beam nozzle also.

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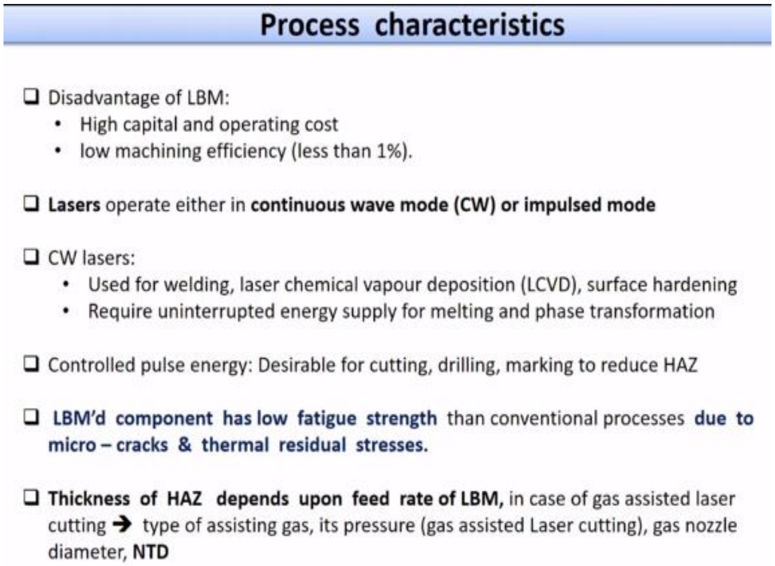

So process characteristics we shall discuss now what are the process characteristics of this laser beam machining. So what are the disadvantage of this laser beam machining? The high capital cost of this laser beam machining system and also high operating cost; high capital cost, high operating cost and its machining efficiency is less than 1% so which is very less so that is why it becomes very competitive with the other conventional machining operations.

So high capital cost, high operating cost, also low machining efficiency less than 1%. So this lasers maybe it can operate in the continuous mode or it can be operated in the impulse mode. Continuous lasers are used for welding purpose, laser chemical vapour deposition, and surface hardening where continuous source of energy heat input is required for welding for hardening operation. So clear uninterrupted energy supply for melting and phase transformation uninterrupted energy supply for melting and phase transformation is required.

Now controlled pulse energy which is desirable for cutting, drilling, and marking to reduce the heat affected zone. So controlled pulse energy is used which is desirable for cutting, drilling, marking to reduce the heat affected zone. So laser beam machine component has low fatigue strength than conventional processes due to micro-cracks and thermal residual stresses.

So thickness of the heat affected zone depends on the feed rate of the laser beam machining, in case of gas assisted laser cutting types of assisting gas also helps to reduce the heat affected zone and its pressure gas assisted laser cutting, gas nozzle diameter and also nozzle tip distance. These are the main important parameters to reduce the heat affected zone during laser beam machining because laser beam when huge amount of heat source actually concentrated into the workpiece surface so it heats up and small amount of material is melted and vaporized and surrounding materials actually there is a phase down transformation occurs so heat affected zones actually is obtained which is not desirable.

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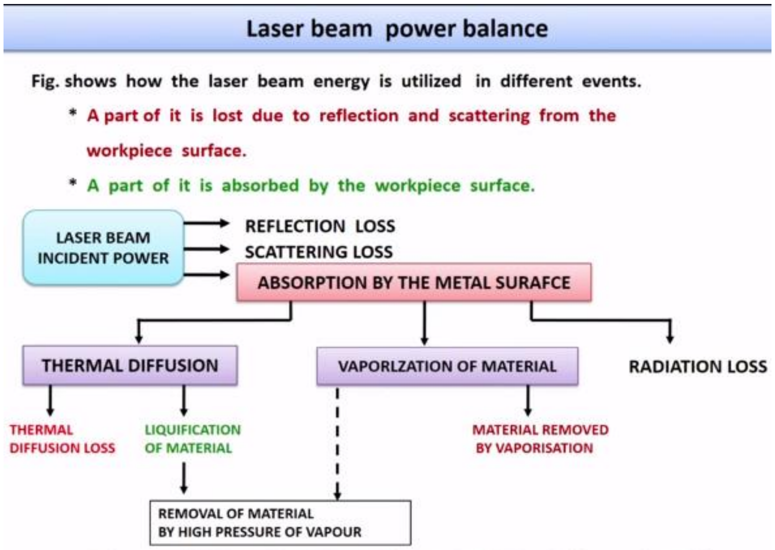

FIG. A LASER BEAM POWER BALANCE DIAGRAM FOR LBM [Yee et al, 1994]

So laser beam power balance how this power actually distributed during laser beam machining. So this laser beam machining during experiments this power is actually distributed in different ways. So a part of the heat source is lost due to the reflection and due to the transmission and due to the scattering from the workpiece surface. So a part of the heat source actually, laser light actually it is reflected or scattered so it is lost. A part is actually absorbed by the workpiece surface. It is absorbed by the workpiece surface.

So what are the different losses are there, laser beam incident power, reflection loss, scattering loss, and part of the beam is actually absorbed by the metal surface. So which is actually absorbed so it is thermal diffusion is there. So there is a thermal diffusion loss and part of this diffused heat into this workpiece material is used by the melting of the is used for the melting of this material and part of the heat is used actually for the vaporization of the material and part of the absorbed heat actually there is a radiation loss is also there. So absorption by the metal surface there is a radiation loss is also there. So whatever this diffused layer diffused thermal heat which is used for this melting of this workpiece material and vaporization of this workpiece material is there. So these 2 things actually helps in removal of the material by a high pressure of vapour.

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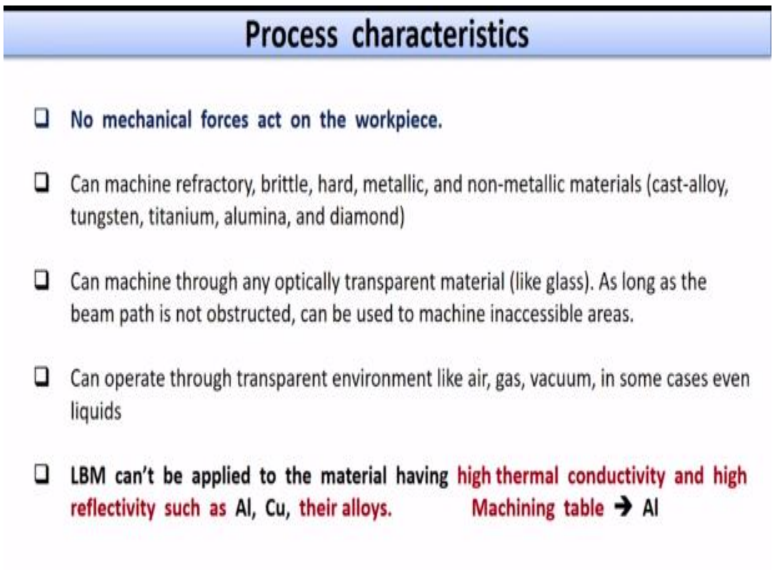

So process characteristics, no mechanical forces are acting on the workpiece surface. So that is why this laser beam can be used for thin and delicate workpiece also as the no mechanical forces are used on the workpiece surface. Can machine in a brittle refractory material, hard metal, metallic metal, nonmetallic materials, cast alloy, tungsten, titanium, alumina, and diamond. Very hard material, high strength temperature resistant materials can be machined by this laser beam machining process.

So it can machine any optically transparent workpiece material as long as the laser beam is not obstructed by the workpiece material as long as it passes through or transmitted through any workpiece material it can be utilized. So any inaccessible areas, so if this laser beam is not obstructed this laser beam can be used for this machining purpose like in transparent glass. So through glass actually laser beam can pass so it will not melt the glass.

So if it is obstructed by the workpiece just below the glass it will do the machining operation on the workpiece. So it can operate through transparent medium or environment like air, gas, vacuum or in some cases even liquids also.

One disadvantage is that so this laser beam cannot be utilized applied for material having high thermal conductivity and high reflectivity like in aluminium and copper so they are actually these 2 materials they have actually high thermal conductivity and high reflectivity so that is why machining of these 2 materials is difficult by laser beam machining process. So that is why most of this laser beam machining in laser beam machining this machining table are actually made of by aluminium workpiece.

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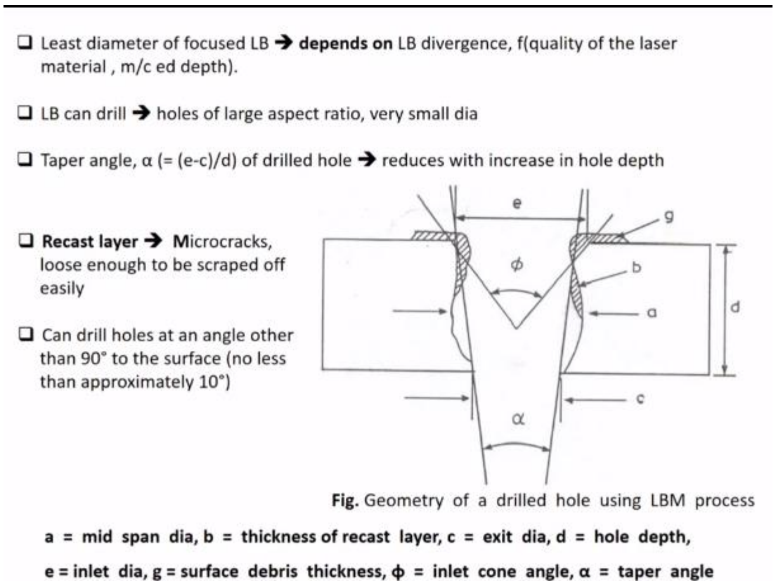

So least diameter of the focused laser beam depends on the laser beam divergence which is a function of quality of the laser material and it is a function of machine depth. So laser beam can drill holes of large aspect ratio means large length to diameter ratio, high aspect ratio holes can be machined by laser beam machining process.

Now here you can see there is a hole generated by the laser beam machining process. So here you can see this one it is the recast layer which is deposited on the workpiece surface. So this is the surface debris thickness. Now here this is the recast layer. It is deposited at the entry site of the laser and this is the exit site of the workpiece so at the entry site this taper angle is alpha and at the exit site this taper angle is sorry phi, at the exit side this taper angle is alpha.

So here at the entry this diameter is e, diameter of this hole at the inlet it is e. So b is the thickness of this recast layer which is deposited whatever this molten material it is redeposited into the workpiece surface. So these are actually very brittle and micro-cracks are there. So we have to remove this recast layer before using these holes for further operation.

So a is the mid span diameter, b is the thickness of this recast layer, c is the exit diameter, d is the hole diameter hole depth, is the hole depth, e is the inlet diameter, so g is the surface debris thickness and phi is the inlet cone angle, and alpha is the taper angle. So this recast layer which is shown here micro-cracks it has micro-cracks and loose enough to be scrapped off very easily. So in laser beam machining process you can do holes other than 90 degree also on the workpiece surface so no less than approximately 10 degree.

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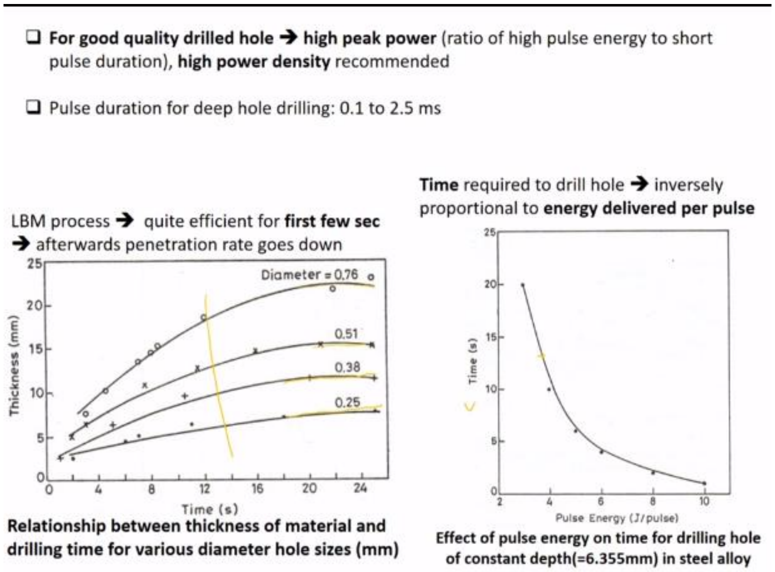

So for good quality drilled holes high peak power is required so ratio of high energy pulse energy to short pulse duration and high power density also recommended. So pulse duration for a deep hole drilling is 0.1 to 2.5 ms. So here you can see laser beam thickness of the workpiece material machined by this laser beam with time.

So with time how the thickness of the machine hole is made drilled. So you can see this laser beam machining process is effective for a first few second where thickness is increases with time but after some time you can see it is become flat. So its efficiency reduces after some time. So initially so this machining rate is very high thickness of the diameter, thickness of the drilled holes actually increases with the increase in time but after that its machining rate efficiency actually reduces. Here you can see this is the time, this is the pulse energy per pulse.

So time required for drilling holes is dependent inversely proportional to the pulse energy per pulse, energy per pulse. So if we have a high energy per pulse then we need less time to drill the holes. If we have a less pulse energy, less energy per pulse then we have a less time, we have a we need actually high time to drill the holes. So this energy required or time required for the for machining holes is inversely proportional to the energy per pulse.

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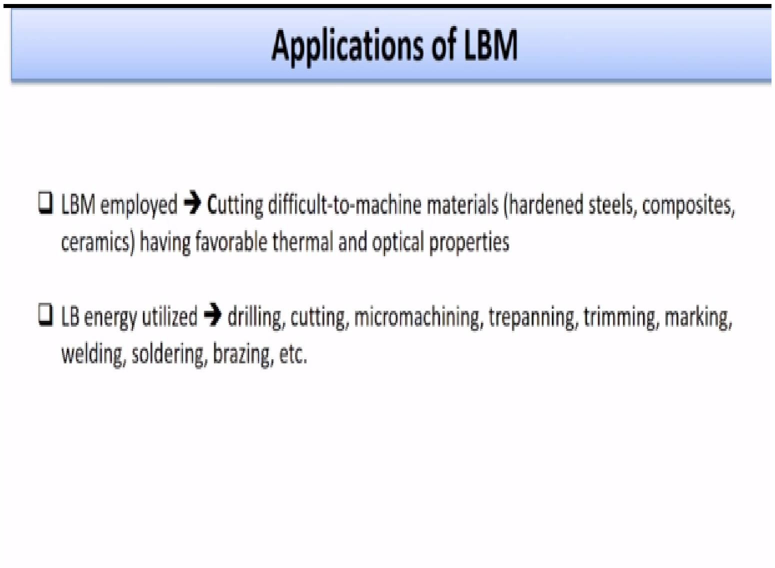

So there are different applications of laser beam machining process. So laser beam machining is utilized for cutting difficult to machine materials like hardened steels, composites, ceramics having favorable thermal and optical properties. So laser beam energy is utilized for drilling, cutting, micromachining, trepanning, trimming, marking, welding, soldering, brazing, etc., for different applications it can be used. One of the application, main application by using this laser beam is the drilling operation.

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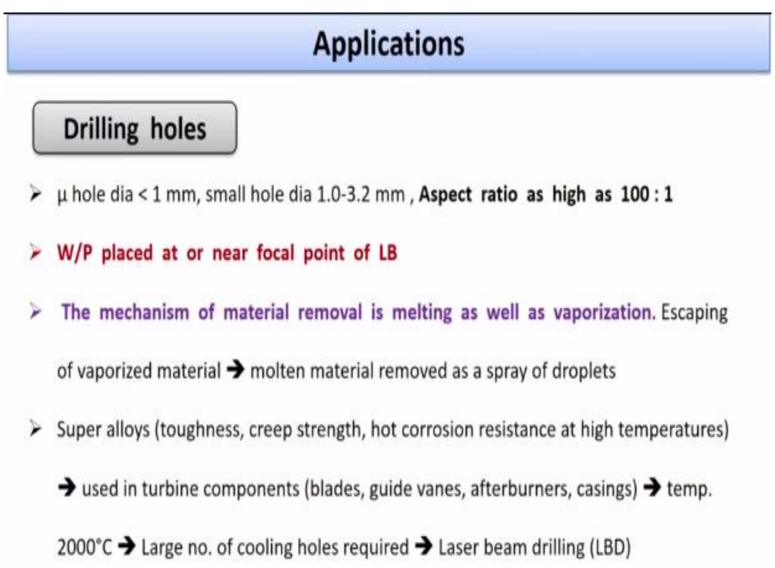

Micro hole of diameter less than 1 mm can be drilled by this laser beam machining process. Small hole dia 1 to 3.2 mm with aspect ratio 100:1 can be made by this process. So workpiece is placed at or near to the focal point of laser beam. So mechanism of material removal is melting as well as vaporization. So escaping of vaporized material when this material is vaporized material escaped outside from the drilled holes at that time it removes whatever this molten materials are there is removed by the spray as a spray of droplets.

It is removed as a spray of droplets. Super alloys are used actually because of their high toughness, high creep strength, hot corrosion resistance at high temperature. So these are super alloys are used in turbine blades component like blade, guide vanes, afterburners, casings. These are the components of turbine blades are used by or made by super alloys. So where temperature is more than 2000 degree centigrade.

So large amount of cooling holes are actually required in this turbine blades. So this cooling holes actually made by laser beam drilling operation. So laser beam drilling is used for drilling miniature holes in diamond dies which is used for wire drawing operation. In sapphire or ruby bearings, which is used in watches for making small small holes these are used in watches.

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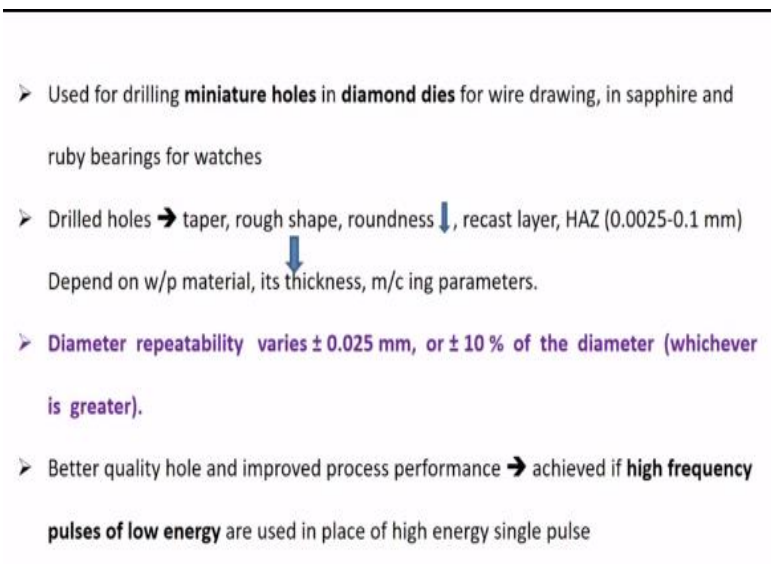

So drilled holes may be taper, rough shape, roundness, reduces recast layer actually is there on the drilled zones, heat affected zone is there. It is 0.0025 to 0.1 mm. So it depends on the workpiece material, its thickness, and machining parameters. So diameter repeatability is plus minus 0.025 mm and or plus minus 10% of the diameter whichever is greater. So better quality hole and improved process performance is achieved if high frequency with low energy pulses are used. So in that case we can get better quality holes with improved process performance. So high frequency low energy pulses are used for better quality holes. So for if we use high energy single pulse then these are the defects like recast layer heat affected zone taperness will be more.

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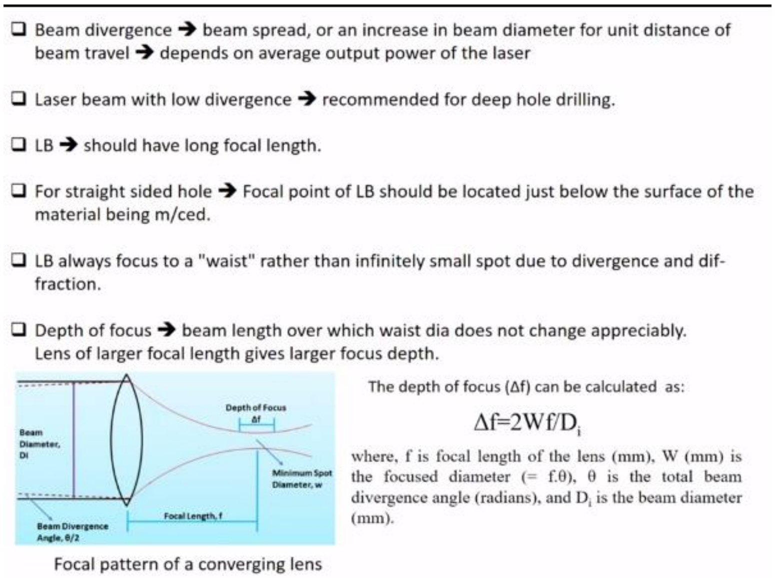

So beam divergence is called beam spread or an increase in the beam diameter for a unit distance of beam travel. So it depends on the average output power of the laser. So laser beam with low divergence is recommended for deep hole drilling operation. So laser beam with having high focal length is used is preferable for straight sided holes to be generated focal point of the laser beam should be kept just below the surface of the workpiece. It should be located just below the surface of the workpiece to be machined.

So laser beam always focuses to a waist shape rather than into a infinitely small spot due to the divergence of this laser beam and its diffraction. So always you will see a you will see this kind of waist shape is generated when it is focused by a lens so it is not focused into a small spot so this kind of depth of focus on the depth of focus this waist shape actually constant.

So this is the on the depth of focus this is the minimum diameter of the laser beam. So this is the minimum diameter of the laser beam on this waist shaped zone so this length of this waist shaped zone is called the depth of focus. So your workpiece should be kept workpiece surface should be kept at this depth of focus only. So depth of focus beam length over which the waist dia does not change appreciably. So lens of large focal length gives larger depth of focus.

So this depth of focus can be calculated del f equal to 2Wf by Di. So Di is the beam diameter and W is the minimum spot diameter, f is the focal length of the lens in millimeter W is the focal diameter focus diameter which is equal to f into theta and theta is the total beam divergence angle in radians and Di is the incident beam diameter.

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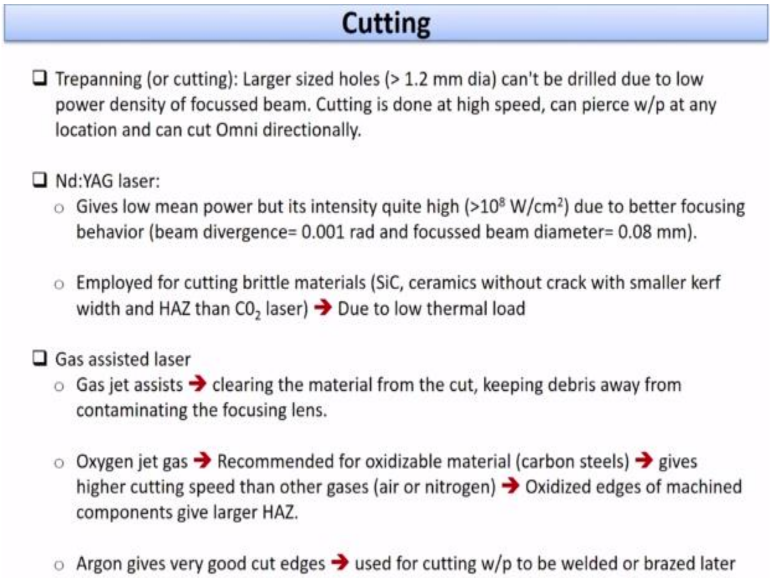

So laser beam can also be used for cutting purpose trepanning operation or cutting so laser large size holes more than if the diameter of the hole is more than 1.2 mm can be cut by this trepanning operation. So in this trepanning operation instead of cutting the melting and vaporizing the total volume of material so along the periphery of the hole actually laser beam actually passed along the periphery of the hole and so that total amount of area can be removed. So cutting is done at high speed if you are doing the trepanning operation, can pierce the workpiece at any location and can cut omni directionally in any direction you can cut. Nd YAG laser gives low mean power but its intensity power intensity, power density very high it is 10 to the power 8, more than 10 to the power 8 watt per centimeter square.

So because of its high focused better focusing behavior beam divergence is very less 0.001 and focused beam diameter is 0.08 mm. So that is why this Nd YAG laser is used for cutting brittle materials, silicon carbide, ceramics without crack with small kerf width and small heat affected zone than CO2 laser. So because of this low thermal load in case of Nd YAG laser. Gas assisted lasers, gas jets actually assist for clearing of the material from the cut and keeping debris away from the contaminating the focusing lens. Oxygen jet gas also is also used for oxidisable material to increase the cutting rate. So it is recommended for oxidisable material like carbon steels. It gives high cutting speed than the other gases like air or nitrogen. It oxidises the edges of the machine components and give larger heat affected zone. So argon it gives very good cut edges used for cutting workpiece to be welded or brazed later. So argon give good cut edges.

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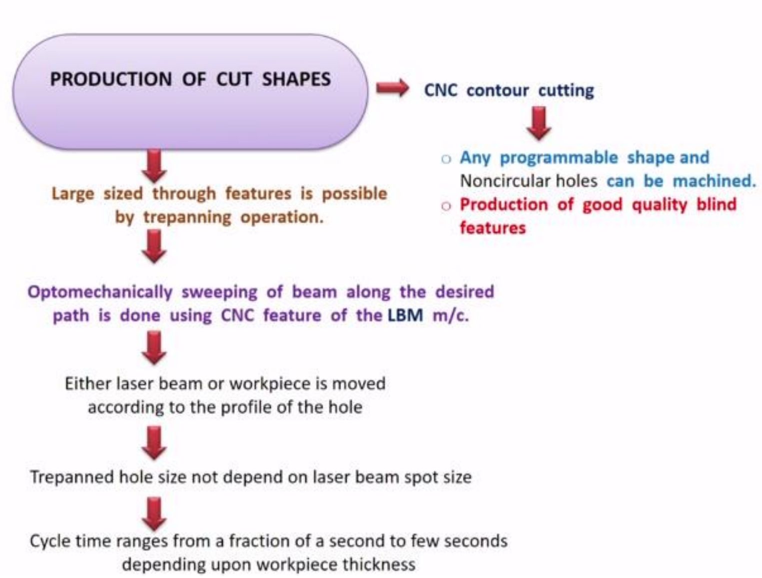

So production of cut space by a CNC contour cutting. So any programmable shape or noncircular holes can be machined by CNC. Production of good quality blind features also can be machined. So large sized through features is possible by trepanning operation. Optomechanically sweeping the beam along the desired path is done by using a CNC feature of the laser beam machine. Either laser beam or workpiece is moved according to the profile of the hole and trepanned hole size not depend on the laser beam spot diameter. Cycle time ranges from a fraction of a second to few seconds depending upon the workpiece thickness.

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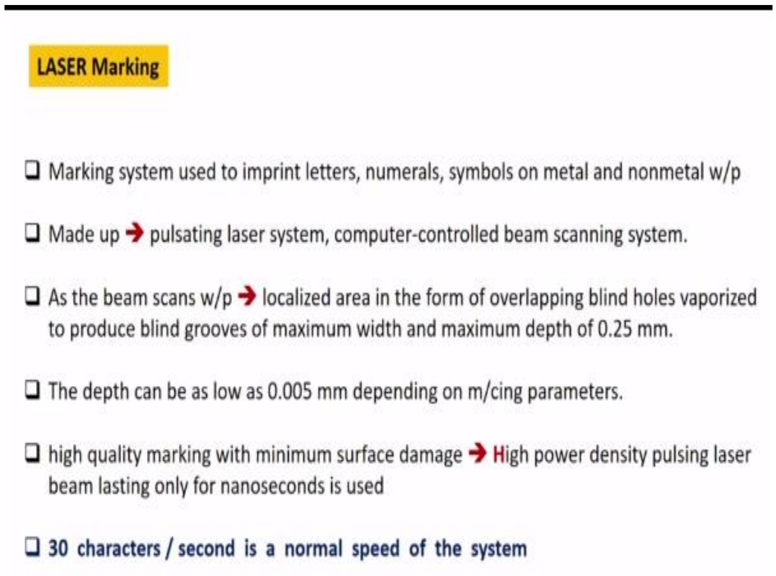

So laser beam also can be used for marking operation. So most of you might have seen that this marking on a name plate is done in front of this office. So this name plates are can be marked by this laser beam on a metallic or nonmetallic part. So marking system is used to imprint the letters, numerals or symbols on a metal or nonmetal workpiece. So it is used by a pulsating laser. So you cannot do the marking operation by a continuous wave laser so it is used by a pulsating laser. So also you need a computer controlled beam scanning system.

So as the beam scans the workpiece localized area in the form of overlapping blind holes are vaporized to produce the blind grooves of maximum width and maximum depth of 0.25 mm. So depth can be as low as 0.005 mm also, so that depth of cut can be measured can be machined 0.005 mm or 5 micron depending it depends on the machining parameters. So high quality marking with minimum surface damage can be done by high power density pulsating laser beam lasting only for a few nanosecond. So 30 characters per second can be machined in a it is a normal speed of the laser beam marking system.

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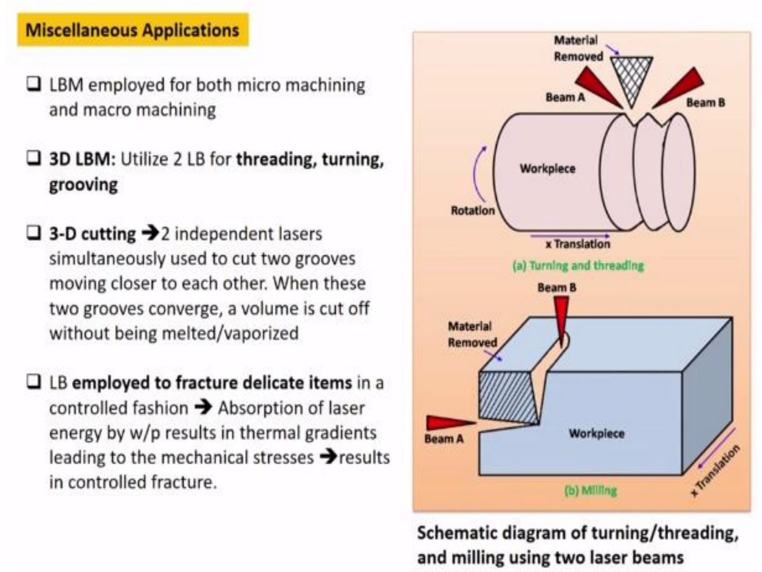

So laser beam can also be used for miscellaneous applications like you can do the turning operation, you can do the threading operation, you can do the grooving operation. So in that case more than one laser heat source more than one independent laser heat source are used. So here you can see this is one beam. Another beam of the laser. So these 2 beams actually it is used to do the these kind of threading operation on a cylindrical workpiece.

So when this 2 beams actually matches at a certain point then volume of material is removed. So here you can see 2 lasers are used for making this kind of grooving operation or milling operation. So laser beam is can be employed for both micromaching or macromachining operations. 3D laser beam utilizes 2 laser beam for threading, turning, or grooving operation. 3D cutting 2 independent lasers simultaneously used to cut 2 grooves moving closer to each other.

When these 2 grooves converge a volume of volume is cut off without being melted or vaporized. So laser beam employed to fracture can also be employed to fracture the delicate items in a controlled fashion. Absorptions of the laser energy by workpiece results in a thermal gradients leading to the mechanical stress so which results in a controlled fracture.

So now with this light I am going to complete this laser beam machining operation. Thank you.