Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Manufacturing Process Technology-Part-2

Module-37
Introduction of Laser Beam Machining Process

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Hello and welcome to this manufacturing process technology part 2 module 37.

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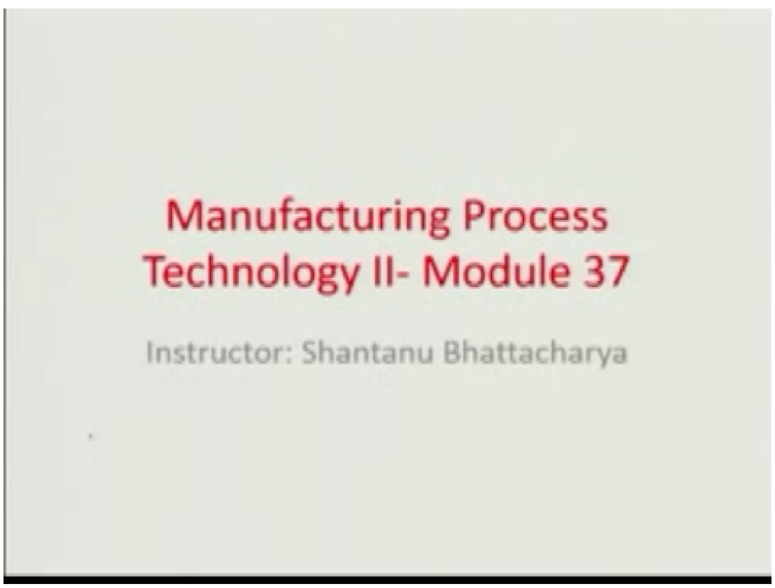

We were talking about E-beam machining in the last module and in context of that we had done a formulation based on the Buckingham pi theorem where we talked about the depth of melting temperature in a E-beam system versus various different parameters like beam power, the work piece melting temperature, the hardness of the material so on so forth. So based on that all of the thermal properties of the material so on so forth.

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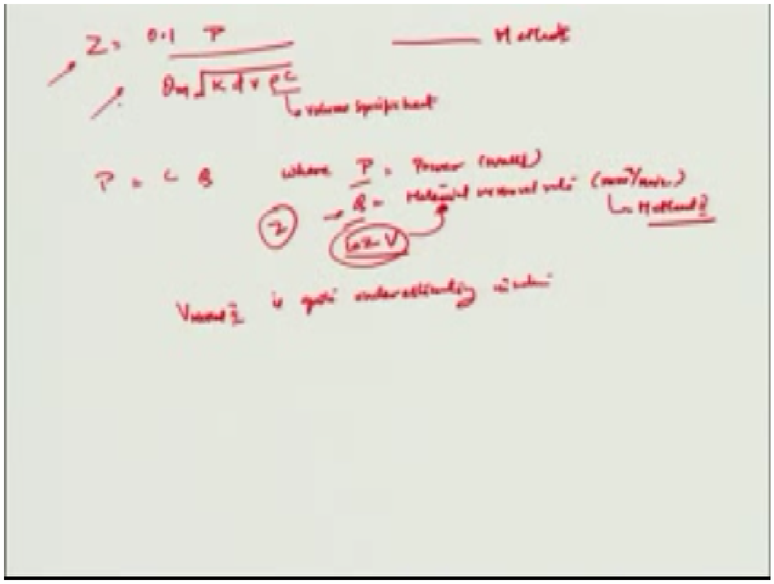

Based on that we had obtained the formulation for the value of Z, the depth of melting temperature which was equal to 0.1 times of the beam power divided by the melting temperature times of root of thermal conductivity of the work piece, times the diameter of the beam, times of velocity of the cart, times ρc which reflects the ρc represents the volume specific heat of the work piece of the material.

So this was one way of formulating what was the Z value and we had earlier obtained, you know neither simple way of estimating this with just the formula power P=C times of Q where P was power in watts, this is beam power and Q was the material removal rate in millimeter cube per minute. That is how we would estimate, you know the depth of melting temperature Z okay. And we found out that between method one right here and method two there was a lot of difference.

And in fact it was very obvious that, you know the method two would under estimate the cutting velocity here obviously, you know the, if you look at the cutting velocity here, the velocity would be in fact the width of the cut times of the depth of the melting temperature that is wz times of velocity. That is how you would calculate the material removal rate here. So from there you found that, if you wanted to estimate velocity through method 2, method 2 is velocity is quite under estimated or quite under estimating in nature.

In fact for a similar problem we found out that the method 2 would yield about let us say almost one fifth of the value of whatever method one would yield. So thus we find out what is the power of dimensional analysis through partially empirical experimental formulation and partial dimension analysis formulation.

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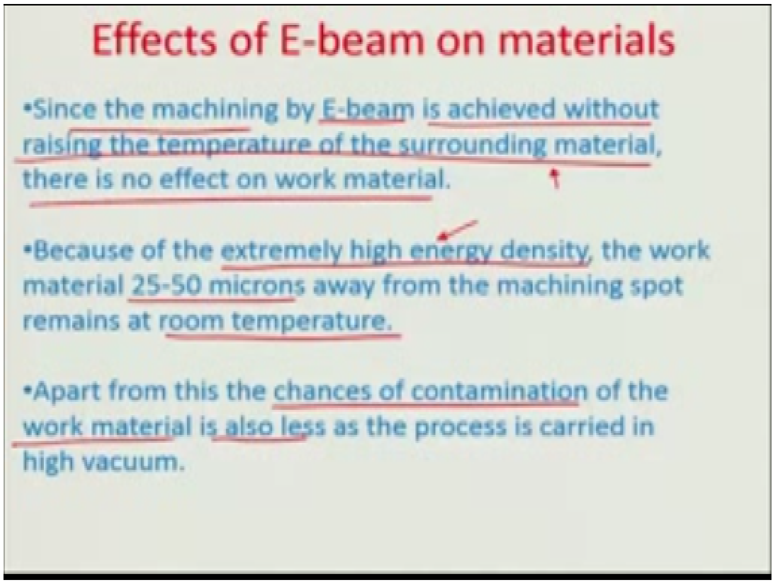

So this is how we concluded the last module, and you know, there was, there are certain other aspects of E-beam that we need to study for example one of the major aspects is the effects of E-beam wanted for materials. So obviously, one advantage that E-beam would offer is that the machine is the change without raising the temperature of the surrounding materials. So you have a system where you can really focus on a very small hotspot.

And therefore, as conventional machining would normally do the remaining portion of the work material is ideal and effected if we use E-beam for doing machine, one of the reasons are obviously the extremely high energy density of the work material and if you look at really the temperature distribution apart from the working zone where the hot spots gets formulated just about 25 to 50 microns away from the working zone you will find to pressure is almost equal to the room temperature.

So there is hardly any chance of although there is a some thermal flow there is some kind of a you know heat transfer between the hotspot in the surrounding areas but that is so limited because of the fact that first of all it is a short lasting process number two is that everything is focused on to one area where more depth verse surface area is recorded in teams of the cutting zone okay because of the use of the high density energy beam.

So the other issue for E beam is that you know the chances of contamination of the worm material is also very less as normally as I had earlier illustrated the beam would necessitate the vacuum column to exits actually and in normal atmosphere you cannot really have an E beam I have to have pretty high vacuum level of the range of 10^{-5} tor or so and chances of contamination from the atmosphere or even minutes mostly a clean system we will be handling etc is more or less to the load lock.

So E beam mean a ways on one hand preferable because of the less contamination or the less damage that it would thermally do to the remaining portion of the work material expect the cutting zone but there is a limitation through of the EDM the E beam is the main limitation is in terms of the work sized because as I had motioned earlier it is not very easy to establish the backing and typically the work piece size would be almost defined by the column size the vacuum column size which is actually housing this whole E – beam system.

And so that creates an additional complexity and very large work pieces may not really be very appropriately machined using e – beam and it necessitates some other kind of process and one other process is which comes to once mind when you look at are the laser beam machining process which really is not a process where which may require such a high vacuum lesser beam machining can be carried out in ambient conditions and it can be carried out in the atmosphere and so we will now focus attention towards this new area of work laser.

Laser in fact has quite a bit high power density it can almost rhyme and rhythm with the E beam process and in fact one other reasons while laser can be used for various applications like laser based joining or vending laser forming and there is a machine and so we would first look into really the basic principles of laser machining and then discuss a little bit of the physics of the lasers and followed by what kind of you know material removal rates would exists in the laser machine will also look at some parametric studies of the different laser in process and try to correlated the one dimensional again heat transfer equation to see what would be the depth of melting temperature in case of different sizes of beams which would exist.

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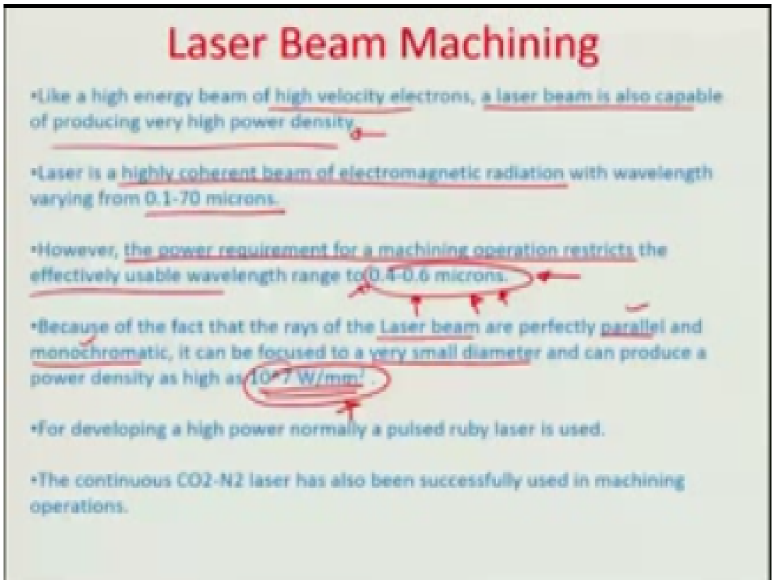

So let us like a high energy beam you know of high velocity electrons have you studied earlier laser beam is also capable of producing a very high power density okay a laser is a highly coherent beam of electromagnetic radiation and the wave length can typically vary between 0.1 to almost about 70 microns there are UV lasers which would exist in the range of about 200, 300 nanometers.

And then you know you can do all the layers is to be about and so microns and so the power requirement for machine operation restricts the effectively usable wavelength range to about 0.4 to 0.6 microns, so point 0.6 microns or 400 to 600 nanometers so this is more or less what you can indicate or what can know is the visible range of the spectrum and the as I think you already have studied earlier about lasers and the opportunity parallel.

At the monochromatic in nature and the power sentence p is that can be hit by in such lasers are typically in the range of about 10^7W/ mm2, so you can have a different mediums for producing lasers, one of them obviously is the pulse in the ruby lesser where they can gas is as well which may produce the amplification and then stimulated in machine step, we find the and brings the laser radiation or you know laser light so there can be ruby lasers and that can be CO2 into lasers they can be also.

Land lasers and so there are different mediums which are use for really laser action or in process and let us look a little bit into what will use in the laser process.

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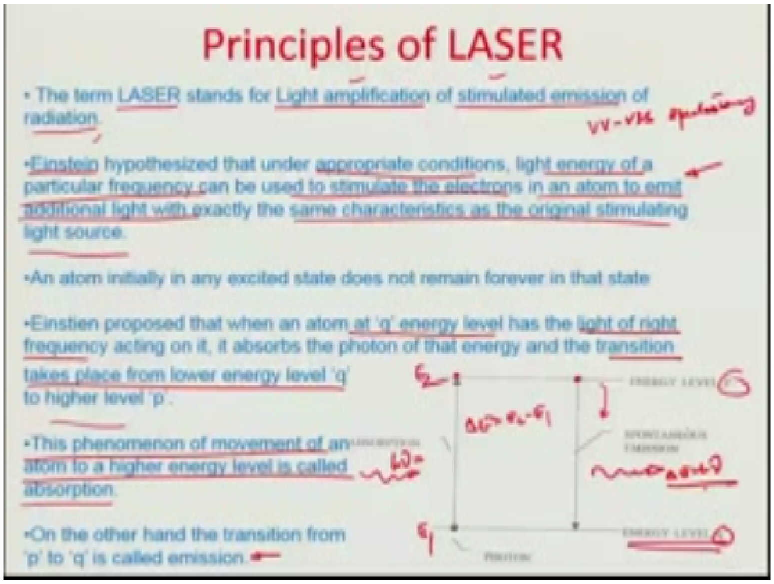

So as the term laser stands you know the some abbreviation of the form light amplification of stimulated emission of radiation, so you have several steps here one is the amplifier step and another is the stimulated dimension step and thought obviously is radiating whatever emissions haven stimulated, and coherently radiating light altogether when the, the stimulated dimension state comes back to normal stage, so the store really was first to emphasis with the hypothesized Einstein hypothesized that.

Under conditions appropriative conditions light energy of a particular frequency would be used to stimulate the electron if an atom to emit the additional light with the exactly same characteristics of the original stimulating light source okay, so the following are steps in order to understand this is a statement, so let us say an atom eventually when excited state and suppose there is an electron the which was earlier at average level Q and it is now recent when available p and because of whatever absorption.

Has happened in terms of a small radiation which is come in the atom, so you know the excited state is a short losing state does not main forever and obviously the electron will jump back again towards its ground state, and when I said proposed is that when an atom at q energy level has a light of the right frequency acting on it let say this h μ = this ∂e is energy by gap difference between E1 and 2 bands so this is domain is one so it absorbs this photon okay.

And there is a transition of this electron that would take place from a lower level q way higher level q so based on this hypothesize in the whole lasing process will define, so this phenomenon of movement of atom way higher energy level is called the absorptions phenomena light in fact the whole use in the spectroscopic is actually based on this absorption phenomena where the molar absorb ability coefficients vary equal to bit with wavelength etc. Son on the other hand the transition from P to Q would be called an emission because as this energy is higher at E2.

So obviously if electron transits back to its level Q from its level P is going to emit a spontaneously a radiation which has this $\delta E = H\nu$ difference you know would which you could not but the question is that if I had several such excited states together in a medium and then suddenly all of a sudden I initiate by a wavelength then the excited states which would happen would all limit together, okay.

So that will create a high intensity number 1, number 2 is highly coherent source of light where there is hardly any face different between all the because you know at if we look at a time clock the addition is all started with the same point of the time clock that is the.

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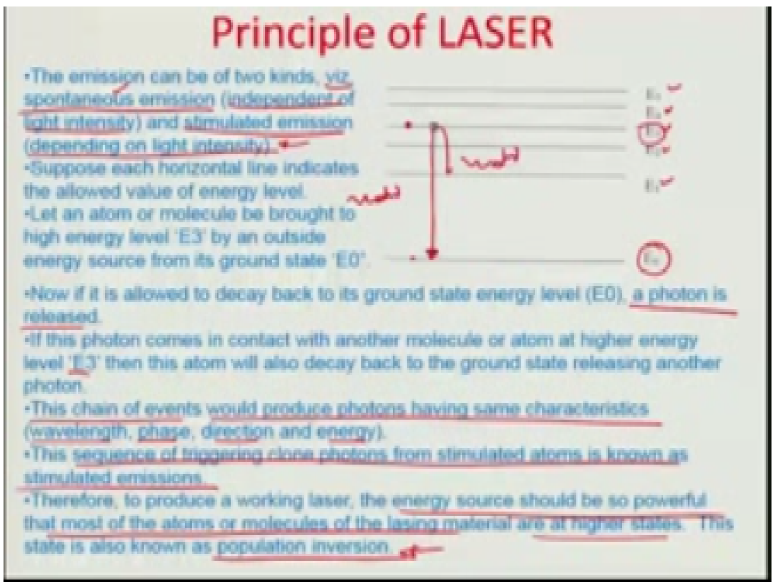

That is the beautiful advantage that a laser has to offer really and so the emission can be of two kinds namely spontaneous emission independent of the intensity of light okay, so it happens atomically and there is another emission which can be recorded as stimulated emission which is really it is dependents on light intensity, so supposing let us say each horizontal line indicates the allowed value of the energy level.

Let us say you have the ground state is 0 and now you have different values of the energy level 0 and 25 and let us let the atom of the molecule be brought to a higher energy level E3 from let us say E0 but an outside energy source so it was earlier here and then it has been brought suddenly to this particular level through a actually energy. So supposing if now it is allowed to decay back and this electron transit back again to E0.

The ground level photon should be released so that is what spontaneous emission is all about, so this photon comes in contact with another molecule or atom at a higher energy level E3let us say and then the atom will also decay back to the ground state releasing another photon, so this is a chain transmission kind of a thing right. So this chain of events would produce photons having same characteristics that is wavelength saying phase same direction and energy saying the sequence of triggering clone photons from stimulated atoms is known as a stimulated emission basically.

So it is a cascading it happens because this energy has suddenly when emitted and hits upon many such states which are already at 3 where all of them will emit together. And this is difference between a spontaneous so the one event here is a spontaneous emissions which is happening but the cascading event which is going on is called as stimulated emission, so you are basically transferring the actually energy into dislocating all the excited electron and state E3.

Of all such atoms which are actually in the excited state E3 and letting the photons all come out together okay as a chain, so therefore to produce a working laser the energy source should be so powerful that most of the atoms or molecules of the laser medium area higher states, so you have to make a need absorb as much as intensity of light okay at sudden energy and you have to ensure that the whole medium has mean inverted.

So this called an inverted medium where in all the atoms that are presented in the excited state rather than the ground state, so there are many ways and mortalities to create a such things one of them obviously is, so one of the ways is by use of a photon flash lamp where it suppose should be such a high intensity of light energy or this photons to observe the you know for absorption to happen in the medium and the medium to get wholly converted to all excited states.

So this change of the molecular state into the excited state is known as population inversion okay, so this is the physical term which is used and so we really emanate how much portion of the medium enormous percentage of the medium is being inverted in order to get a good lasing source, good lasing signal.

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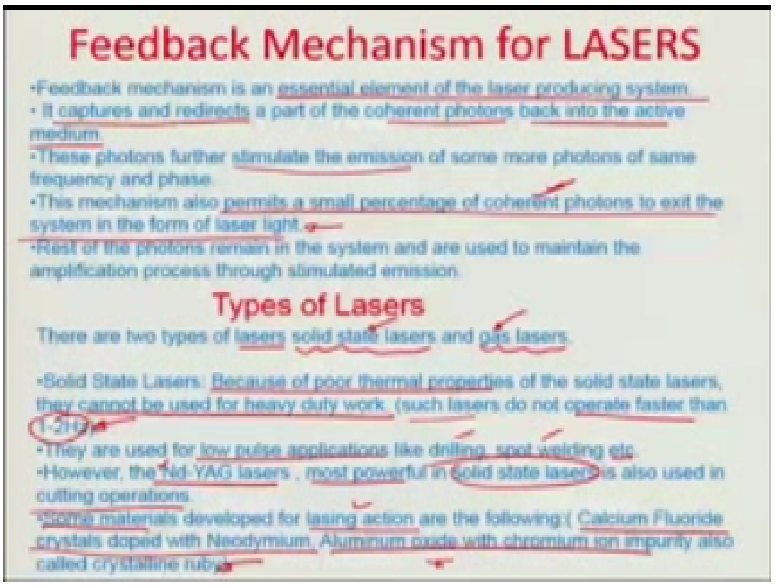

So the feedback mechanism for lasers is a very important factor will determines this correct control of when the stimulation initial should occur or when it should be allow to come out of the lasing system, okay. So the feedback mechanism is essential element of the laser producing system okay, and it captures and redirects a part of the coherent photons which are emitted by this stimulated emission process back into the active medium, so that they can produce further stimulation of the emission.

And so basically i is really about you know trying to capture and trying to keep the medium always activated to the higher energy state so that this process of stimulate conversion continues so it is basically some sustaining kind of process. In the mechanism also permits a small percentage of coherent where photons to exit the system and this whole cut of between how much is going to exit this is I mean how much is going to get pumped back into the laser medium is what typically determines the intensity of laser source.

So you know so step wise if you look at and summary what is going to happen within the medium is that first of all the medium absorbs from a strong source and the population gets inverted to excited states and then there is a spontaneous emission which would happen which would lead to the cascading events and stimulated emission to sort of get produced and so all these photons were together come out as coherent photons and then there is a job of the feedback mechanism to capture a part of it and pump it back into the laser medium.

So that you know always there is an excited state prevalence in a medium and this spontaneous emission keeps on or the simultaneously emission keeps on happening and what about amount of the signal is send outside the lasing domain is what determines a lasing density and these intensities are very, very high. So basically you can say that the part of the signal which comes out is really the useful energy for machines because you can use this energy for doing different lasing activities or lasing machining or vending activities.

The rest before done obviously would try to the main within the confines of the system and this would be utilized to sort of sustain the laser okay, and sort of sustain the stimulated emission of the medium of the laser. So if you look at the different types of lasers there are lasers which can really depend on the medium that are been used to produce so they can be solid state mediums like a ruby crystal for example.

So if such a medium exist you can call it solid state laser, you can also have gas like a helium vein system or a carbon dioxide, nitrogen system which can produce the same lasting effects and so if that system happens so it is called a gas laser, okay. Typically solid state lasers, because poor thermal properties cannot be used for heavy duty work so that has to be always remember okay they are very slow laser they do not operate very fast may be you know the frequency operation frequency at the most is about 1 to 2 hertz okay, they are however used for some pulse applications you can have let us say drillings spot welding etc where a portion of the material has to be intensely heated. So there is not really much of pulsation kind of or pulse setting kind of system which would be needed.

So there you can really use solid lasers quite a bit and the EMB yard lasers are sort of most powerful as for as all the solids state take lasers go and the yard lasers are quite often using cutting operations and some of the other materials which have been target at laser medium and have been reported from time to time include calcium fluoride crystals doped with neodymium aluminum, aluminum oxide with chromium ion impurity. So this is also known as the ruby crystals so on and so forth. So these are the various types of solid lasers which available we look at gas lasers.

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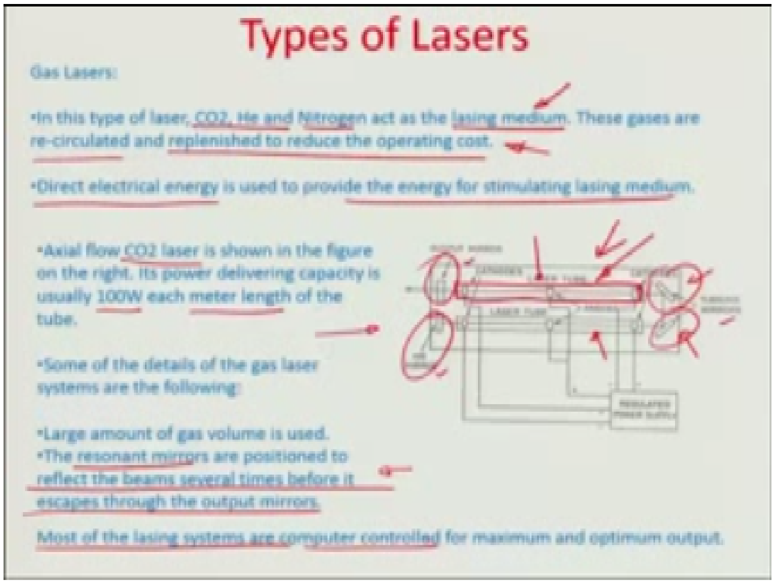

You have CO2 helium and nitrogen which are really very good medium which would do the population inversion process so that the lasing could happen. The gases are almost obviously re circulated and replenished to reduce the overall operating cost of the laser, direct electric energy is used to provide the energy for stimulating the lasing medium here you can see one such schematic of gas laser so there is set of cathodes and again anodes between which the resealing medium.

So this CLE is the laser tube here you can see the boundary of the laser tube here which can be filled with typically a medium it can be a gas for example and there are again some mechanism here like mirror etc and some turning mirrors to which you would actually pumped back part of the system you know at part of the intensity that is generated through stimulated demission back in the laser tube okay.

So there is a part of some feedback control here which is being illustrated, so axial flows your two lasers are what is shown here actually I will just give you some illustration about the kind of powers that it can produce so it can about produce what 100 watts per meter length of the tube that we are looking at here in this case so there are two different parallel tubes here for example.

So the resilient mirrors in such a system can be seen in both sides here these are the output and there is like resilient mirrors and this is like the turning mirrors.

They are positioning to reflect the beam several times so that you can pump the laser to a certain high power value and then once that power value is achieved theresholding power value is achieved you could actually retain a part and give a part of this signal outside the lasing source. And obviously you have to have a quick control system for all these power pumping issues and power retaining visa of is power transmission issues of the laser.

So therefore they are all computer control for maximum and optimum output. Some other facts regarding the laser or you know that if you look at the overall efficiency of the laser beam machining it is really not very high it is about almost you know 0.3 to 0.5 % in most of the cases and let us look at some of the performers parameters or performers metric of deserving machining process for example.

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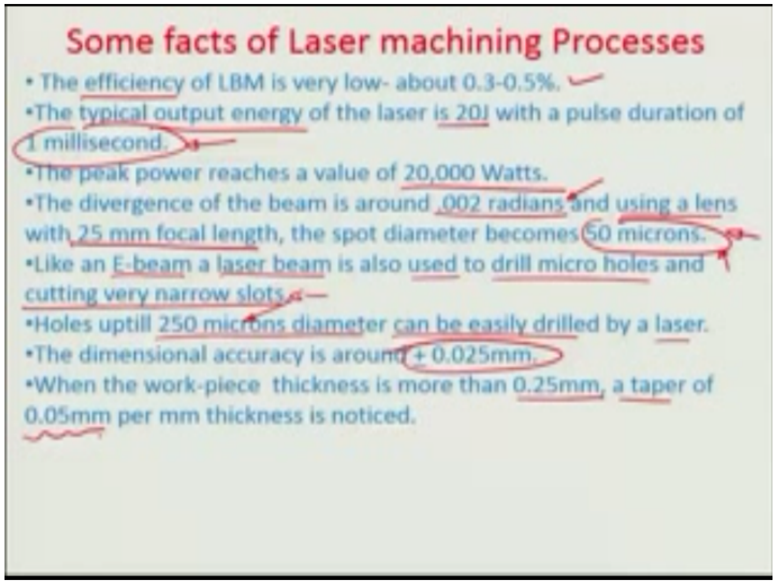

So we have the efficiency which is about o.3 to 0.5 % very low typical output energy of the laser is about close to 20 joules, you can have a pulse duration of almost 1ms this has gone to now quite small values there are even come to second laser which have been produced by good amount of you know molecular level controls system which can be brought in by various modern physics techniques.

The peak power reaches around almost 20kw in most of laser systems the divergence of the beam is very small because it is highly, highly parallel source of light that comes out so you have a mirror to certain direct the light outside the laser medium so you have overall divergence of 002 reduce using the lens where about 25mm focal length, spot diameter becomes as lower as the 50 microns.

There are other versions now of modern results which will go even further down to almost about lithography all most above over micron range but that really involves very costly optics so like E-beam laser beam is also performed or directly used machining for example it could drill micro holes and it would cut narrow slots in similar manner holes up to about 25 microns to 250 microns diameter or routine drill with laser.

Obviously this limit can go down further required the accuracy is almost in the range of about +-0.025mm you have to remember that divergence of beam it would happen and so the intendent values of the dimensions which are normally planned for by laser machine can be done very easily.

When the work piece thicknesses is more than about 250 microns there may be a taper which is very small again about 0.05 mm per millimeter thickness and this taper is mostly because of the wave that heat transfer process is happens and also you may be the hotspot is really at the surface of the work piece and so therefore there would be limited heat diffusion which would take place which any lead to this tape reaction.

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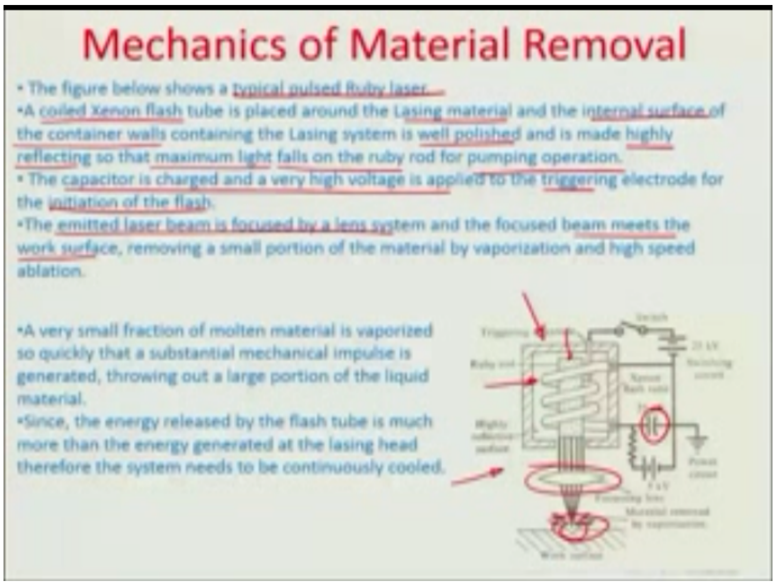

Let us look at how will laser system is really schematically represented so you have this solid laser here it would be rod you can see this producing the population membration so it is pulse laser system that is been represented here there is a coil of the you know Zeon flash tube which would be the principle radiation source which would really crystal for a tool invert cross sectional population.

So there is the population invergence of root will be done by the Zeon here the Zeon power is very high of flash tube which can do this and which can substantially converted the root will be again to the inverted source so coiled using on flash tube is placed around the laser material internal surface of the container walls containing the lasing system are very well polished made up highly reflecting surfaces that idea is that maximum light should fall on the ruby rod of this non flash tube for pumping operation to happen.

There is the capacitor as there you can see here which is charged to very, very high voltage apply together the voltage to be the flash tube so that you know you can initiated the flash all of us suddenly in to the radium beam diameter laser beam is focused by a lens system further you can see the lens here okay.

And on the focus being needs the work surface a small portion of the material can be vaporized further because of the beam mattering interaction will look at the details in the next module this module has to close now it is time up but we will talk about the pulse laser would be the system in work it would be in term of surface scanning of work surface could be machine on the surface in the next module so till then thank you and goodbye.

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