Advanced machining processes
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Lecture 27
Laser beam machining

Welcome to the course on advanced machining processes today is the second lecture of laser beam machining. I have already discussed the production of the lasers, how it is to be done? What are the various kinds of lasers? Mainly solid laser, NDR laser and gas lasers say Co2 laser. What are the characteristics of the laser beam has also been discussed and then I explained the working principle in detail of laser beam machining where the mechanics of material removal is melting or melting and vaporization depending upon the intensity of the laser beam and the work piece material that is being machined.

After that I have also discussed the function of some of the parts of the laser beam machining especially the feedback mechanism of the laser beam machining system. Now the most important thing of this principle or the laser beam machining process is the applications as we will see there is no constraint as long as electrical conductivity of the work piece material is concerned but definitely thermal conductivity of the work piece material affects the performance of the laser beam machining system.

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It is not only Manufacturing or machining where laser beam has lot of applications there are various processes there also it has applications. So I am going to give a brief of all these applications in different fields of life.

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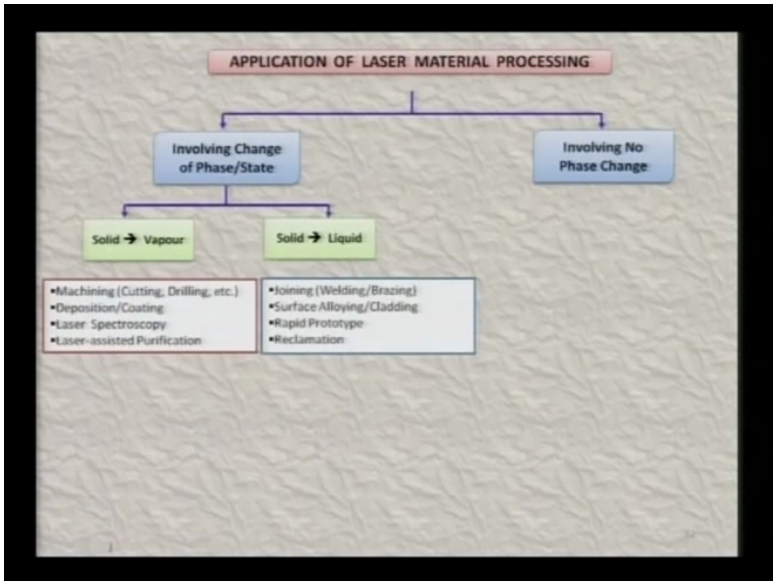

Now the applications of this laser beam can be or in material processing, now this material processing can be done in different ways one of them is involving the change in the phase or the state of the work piece material that is being removed that means the piece material is solid than the material to be removed may change its phase, it may be in liquid state it may be in the vapor state.

Second types of applications are there where there is no change in the phase of the work piece material as we will see one by one. Solid may change to the vapor directly depending upon the intensity of the heat and the temperature at which it is going to remove the material. Second phase is solid first changes to the liquid and then it may change to the vapor may not change to the vapor.

Now in case of solid to vaporization which normally also involves the liquid phase also, it includes the various processes of Manufacturing just like machining. Machining involves creation of different kinds of the features by cutting, drilling, milling etc then deposition or coating, laser spectroscopy, laser assisted purification of the material. It also involves solid to liquid phase which includes the processes like joining processes.

There are various kinds of joining processes which are done using the laser beam that includes welding of the 2 parts in different ways or brazing of the 2 parts. Surface alloying or Cladding, rapid prototyping is the one where laser beams are quite commonly used and then reclamation is another application.

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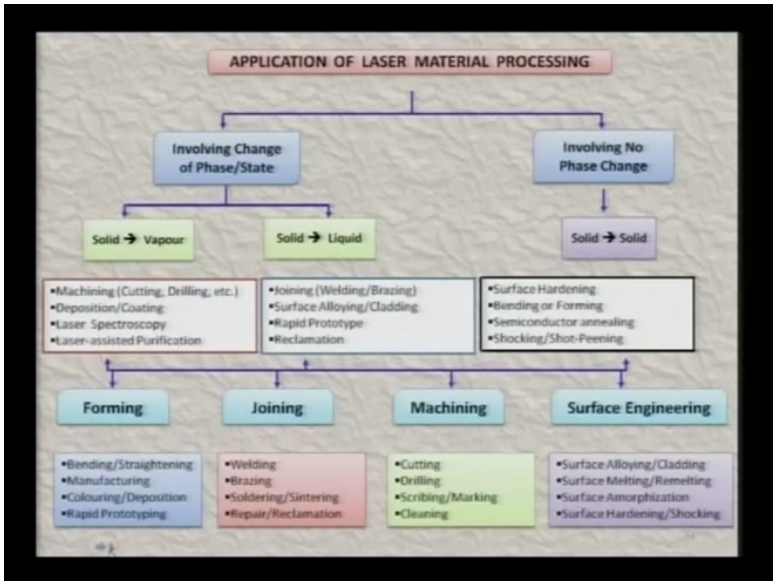

Now solid to solid phase where you do it that is processing of the material from solid and finally when processing also it remains solid it includes surface hardening, bending or forming, semiconductor annealing, shocking, shot peening. So these are some of the applications were material is being processed using the laser beam.

Now when we talk of manufacturing processes, one of the very important Manufacturing processes, forming it includes bending with the help of the laser, the laser heat is utilized for that particular purpose and then due to the thermal temperature gradient the bending of the parts but definitely very small parts and thin parts can be done with the help of laser beam.

Manufacturing various applications I have already mentioned, colouring, deposition, rapid prototyping then joining processes includes welding, brazing, soldering and sintering, repair or reclamation. In machining there are various applications like cutting, drilling, scribing, marking, cleaning and finally surface engineering includes surface alloying or cladding, surface melting, re-melting, surface Amorphization, surface hardening, shocking.

Now before I move to the next line I would like to mention that laser beam is commonly used for macro manufacturing as well as micro Manufacturing. Micromanaging it has lot of application especially I will tell you like laser micro-machining very common I will give you some of the examples here then laser bending for bending the sheets laser is being used commonly and then laser micro-welding.

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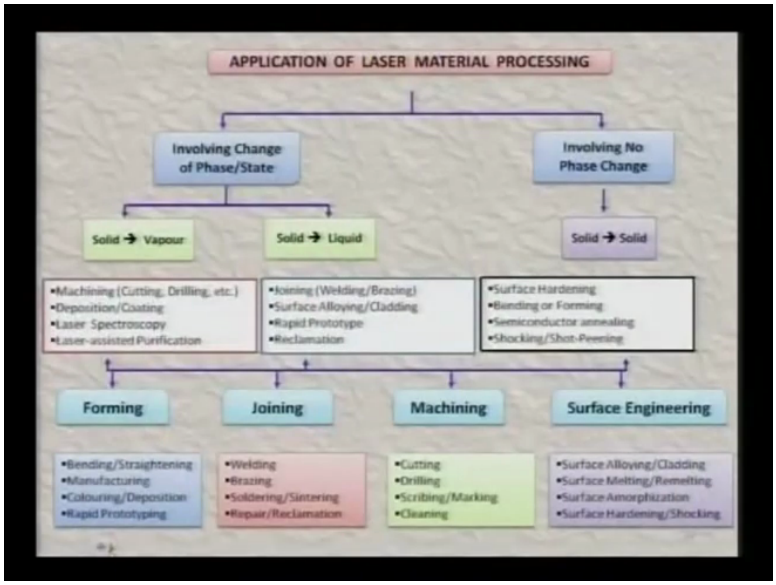

Laser micro-brazing same way is true for laser cutting, micro-cutting, laser micro-drilling, laser micro-marking and so on. So I will give you some of the very important and interesting examples of laser macro-machining as well as micro machining I am not going to cover other applications like welding, brazing etc. I will concentrate in this lecture only for machining that is laser micro-machining which includes macro machining as well as micro machining

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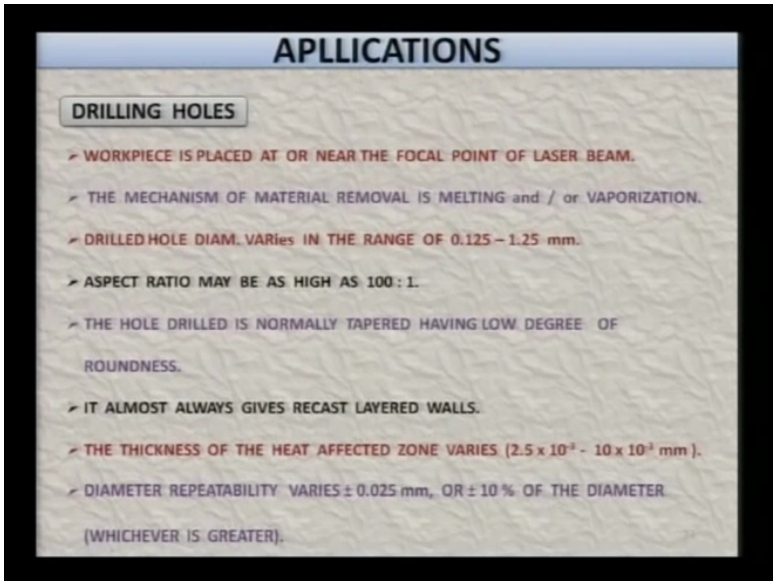

Now drilling of the holes using laser beams the work piece is placed at or very near the focal point of the laser beam, so that the maximum utilisation of the heat energy available due to the laser beam is made. The mechanism of material removal has already been discussed in detail and that involves melting or melting in vaporization both. Drilled hole diameter varies in the range of 0.125 to 1.25 millimetre because it will depend upon the diameter of the laser beam and normally we try to reduce the diameter of the laser beam at the focal point, so that you can have high concentration of thermal energy and normally the largest diameter that one can normally obtain is around 1 millimetre or so. So you can have the range of the drilled hole diameter as 0.125 to 1.25 millimetre.

Then aspect ratio may be obtained and people claim as high as 100 ratio 1 but it is quite on the very high side, normally for macro holes it is very low, micro-holes it maybe little larger but under special condition you can get something like 100 ratio1 which is been claimed by some of the authors. The hole drilled is normally tapered having low degree of roundness; almost always give recast layered walls.

This recast layer I have also discussed when I was discussing the electric discharge machining that this is the thermal for say, so what happens that molten material solidifies before really it is ejected out of the cavity being formed that is why this is known as recast layer and this layer is very hard, its hardness is very high compared to the (()) (9:37) material and this should always be removed before putting this particular part in the subassembly or assembly.

The thickness of the heat affected zone varies in the range of 2.5 to 10 microns and this can be controlled with the help of various laser beam machining parameters and diameter repeatability by laser beam machining process lies between plus minus 25 microns or plus minus 10 percent of the diameter whichever is greater. Now one thing this variation is there, there are some other problems with the hole being drilled I have already shown to you when I was discussing with the long pulses and short pulses.

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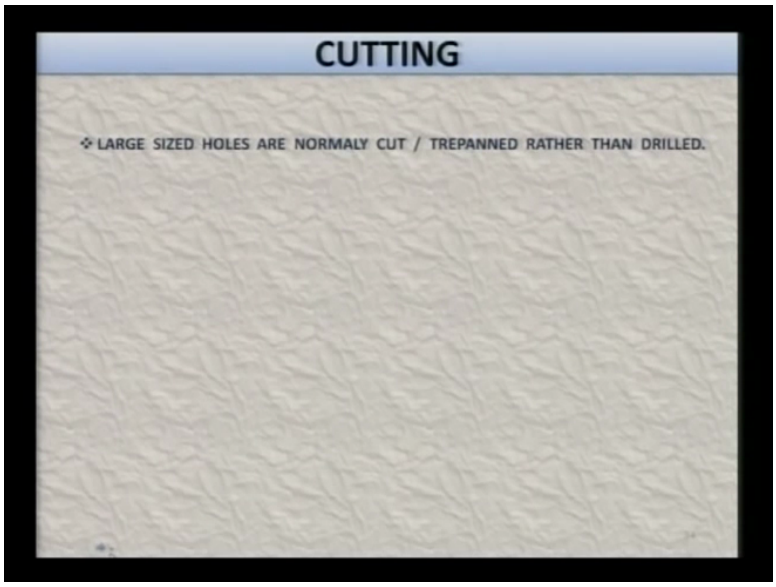

And there are various applications as long inch cutting is concerned. Large size holes are normally cut, trepanned rather than drilling this is very important point.

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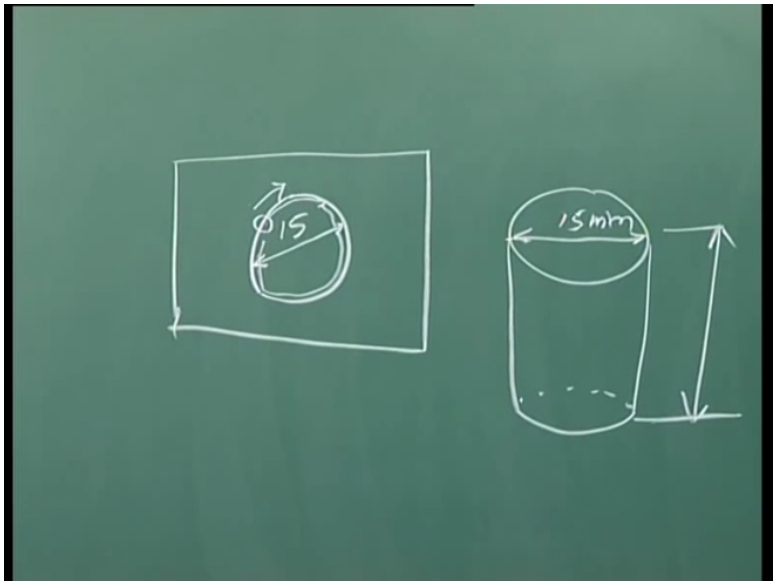

I will just explain to you here on the board that suppose this is a work piece and if you want to cut a hole or drill a hole of around 1 millimetre you can do with the help of the laser beam directly but suppose you want to drill a hole in a very hard material of around say 15 millimetre diameter like this then there is no sense in melting and vaporising the whole of the material this particular 15 millimetre diameter and depth equal to the depth of the hole to be drilled.

So what is the best way in such cases is, you do the trepanning operation that means you cut the material along this periphery of the hole being drilled. So after machine once he have booked it through the whole length along this particular periphery by trepanning operation then what you will get is this particular solid material that has come out of this you will get the desired hole and the diameter of this particular solid part will be around 15 millimetres and what is exact diameter will depend upon on which side of this periphery is cutting the material.

And this depth or the height of this or the height of this solid material is normally not very high it has to be reasonable, so that the laser beam can do the cutting appropriately. Now as we have seen it is a purely thermal process as long a continuous laser beams are concerned or in some cases pulse laser beams are concerned there are other beams also nanoseconds, femtoseconds etc especially the excimer laser which are heatless processes that means in those processes of machining evolution of material takes place rather than melting and vaporization of the material I am not going to discuss it here but I will give you some applications of excimer laser.

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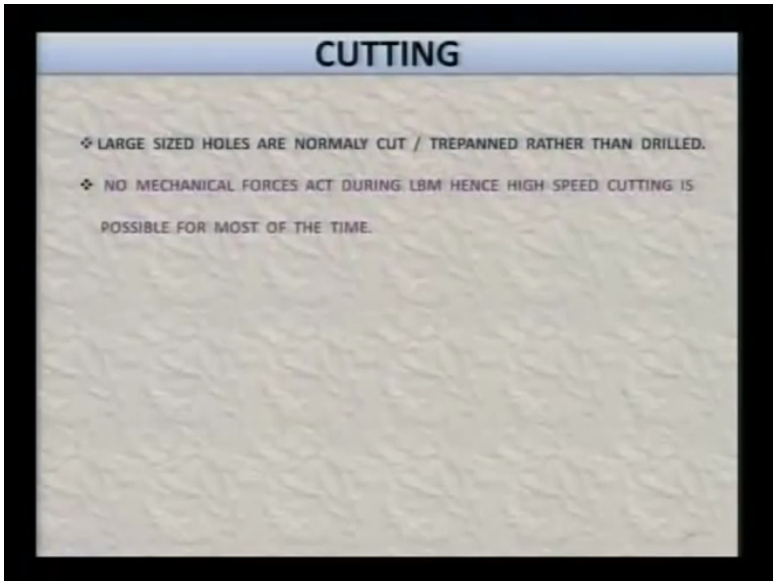

So there are no mechanical forces acting on the work piece during machining process with the help of laser beam hence high-speed or cutting is possible for most of the cases and for most of the time. Here invariably machines available have the CNC feature computer numerical control feature, so that you can program the moment of the beam along the periphery to be cut or machined and it can be done at much faster rate than what you do by conventional processes.

Now along with laser beam as we have seen earlier also in the last lecture that gas is used to aggravate or to increase the machining rate. So gas jet assists clearing the cut material during the laser beam machining, when you are cutting a (()) (14:08) or cavity the molten materials should be ejected out otherwise it will keep consuming the heat from the laser beam. So for rejecting clearing the cavity from where material is to be removed, normally inert gases are used.

Or you can use oxidising gases in case of material that get oxidise to increase the machining rate also but that gas assist in injection of the molten material that is to be removed from the cavity. Oxygen for oxidizable materials gives higher cutting speed because higher material removal rate can be obtained when you have the higher cutting speed but oxidised edges are there and you get larger heat affected zone, HAZ means heat affected zone are obtained. So one has to be careful one should consider that you are going to get the edges which are oxidise because oxygen is being used and there are various materials which gets oxidised in the presence of the high-temperature and oxygen gas.

Secondly the heat affected zone is also larger; we have to take care of both of these things before really edging this particular part in the devices. Argon is a good assisting gas with the help of which you do not get the oxidised edges and cutting edges are also sharp better compared to what you are going to get in case of oxygen.

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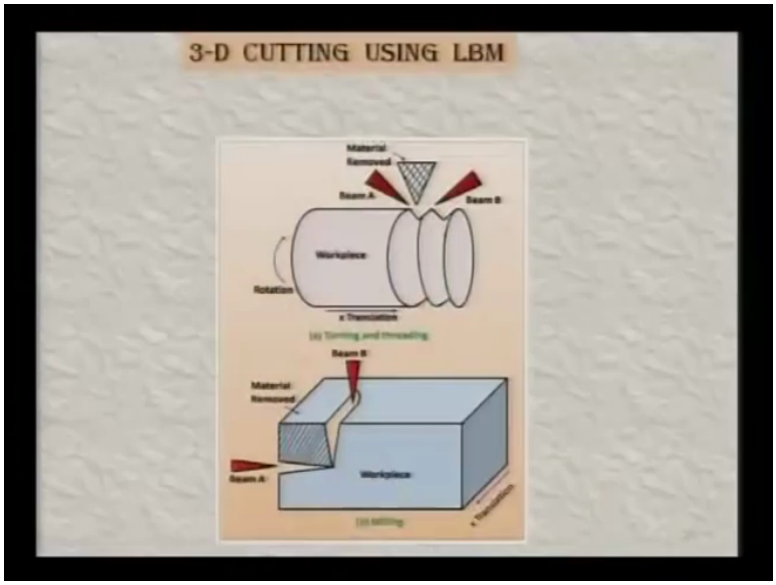

Now normally what we have seen so far is that laser beam machining is, we utilize for 2-D cutting or at the most 2 and a half D cutting but with certain modifications in the laser beam machining system you can use it for 3-D, real 3-D cutting as shown in this particular figure that if you are on the top side if you see if you are using 2 beam's, beam A and beam B both the laser beams in a proper fashion and work piece is rotated then what you can do?

You can cut the threads on the work piece as you do it on the lathe machine during turning operation and this can be very well used economical especially in case of the materials which are very difficult to machine and you can also see at the bottom figure that if you are judiciously using beam A and beam B then you can cut or you can do the 3-D cutting with the help of beam a and beam B and you can remove this as a solid material which can be used for other purpose A. So by some modifications in the system you can use it for 3-D machining also.

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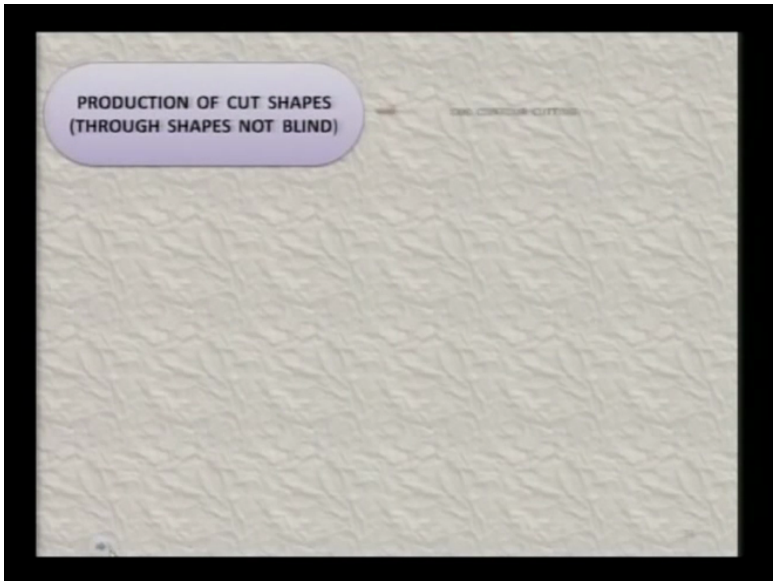

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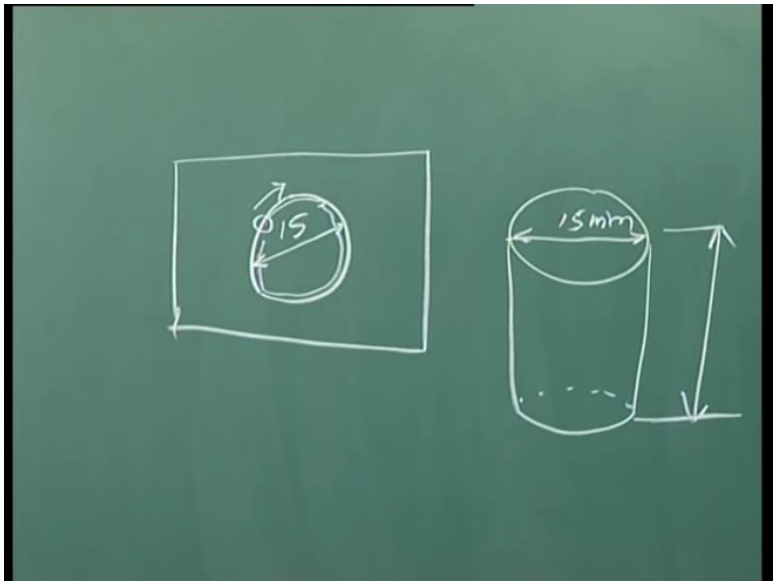

I have already explained that it is easy to cut large size through shapes by trepanning operation using the CNC machining feature rather than melting and vaporising as shown here in this particular figure. So what it says production of cut shapes, through shapes not the blind you can use the CNC contour cutting features, any feature that you can express in terms of equations or you can make the program for it, any program we will shape can be cut or machined by laser beam machining system.

Production of good quality blind feature is normally difficult, this is very good for through shapes, for through cutting and it is really difficult and not a very high quality blind grooves or milling operation can be performed.

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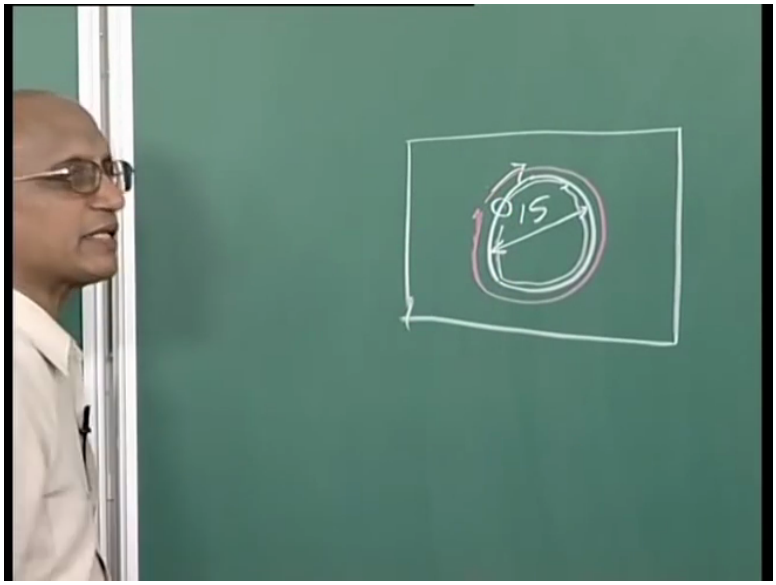

Large size through features are possible trepanning operation as I have explained on the board then optomechanical sweeping of beam along the desired path is done using CNC feature of the LBM machine which I have already explained. That the beam has to move along this periphery at proper feed rate because hole of this material this beam has to cut either in one go hole or this or you may take more than one go that means more than one stop for removing the material by trepanning operation. it depends on the thickness of the work piece or height of the solid material that you are taking out by trepanning operation.

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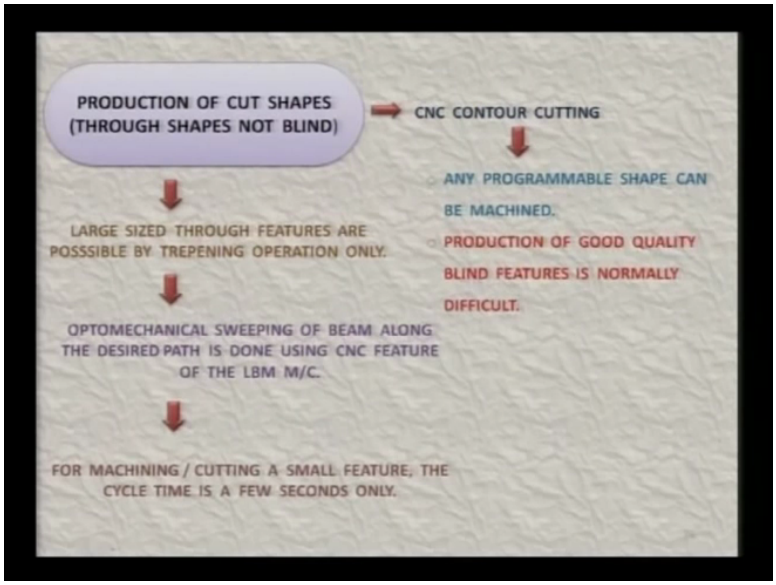

For machining cutting small feature the cycle time is a few seconds for even fraction of seconds depends upon what is the thickness of the sheet and what is the size of the feature that is being machined with the help of laser beam machining system.

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I will give very interesting example of this. Now you see here what is this? Here is hair human hair which you can see at the upper part of the figure and you can clearly see there is written the E X I M E R L A S E R and this letter E X I M E R L A S E R has been written on the human hair with the help of the excimer laser. So now you can think of the capability of excimer laser in marking or cutting the material like on human hair also and bottom part clearly shows how accurately and nicely the letter have been written on the human hair.

So this indicates the capabilities of micro-machining of laser beam setup and this is the excimer laser which is a heat less process, as I mentioned few minutes back that excimer laser gives you heat less process where evolution of the material takes place rather than melting and vaporization, so you can see micro-machining letters on a single human hair, note the clarity of the letter in the close-up view that is bottom part.

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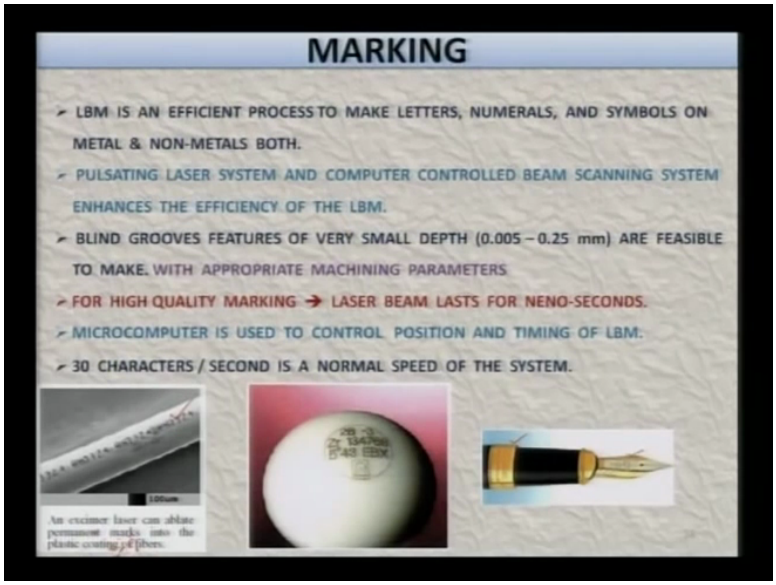

Now here are certain examples of the marking, you can see excimer laser can (()) (21:01) permanent marks into the plastic coating of fibres. Here is a plastic coating of fibres and you can clearly see how nicely the letters have been put on that particular fibre. Here is another example of marking on the ball kind of the part and here are the marking on the very expensive pen tip, old pen tip.

Nowadays people do not use this kind of the pens normally but you can clearly see the marking over here and all this has been done with the help of the laser beams. Here also on the non-metallic part marking is given over there. So for marketing purposes laser beams are very good and they are very fast. Now laser beams is an efficient process to make letters, numerals and symbols on metal and non-metal both as we have seen in these 3 figures.

Pulsating laser system and computer controlled beam scanning system enhances the efficiency of the laser beam. All these processes take very small-time because we are using CNC features of the laser beam machining system otherwise it is now going to be very difficult. Blind grooves features very small depths 5 microns to 250 micron are feasible to make with appropriate machining parameters.

You have to select the appropriate optimum machining parameter then only these Blind grooves etc (()) (22:33) otherwise making of blind groove is rather a difficult task with the help of laser beam machine setup. For high-quality marking laser beam lasts for nanoseconds at a particular point that is why in few seconds or fraction of seconds you can machine these letters or you can do the marking.

Microcomputer is used to control position and timing of the laser beam and normally this much had enhanced further 30 characters per second is the normal speed of the LBM system as long as marking is concerned.

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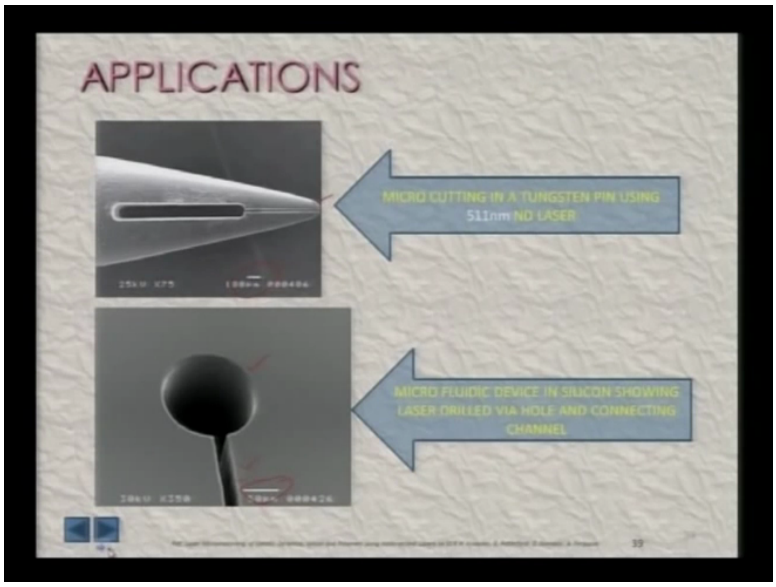

There are other applications of the laser beam, you can clearly see how thin the cutting has taken place this is a bigger (()) (23:26) part and this is a very thin sheet which is connecting this big one with this small one and this is the scale for 100 micrometres, so you can see it is maybe few micron or less then around 10 micron size or so.

Micro-cutting in the tungsten pin using 511 nanometre NDR laser. Now here is a hole which has been connected with the channel. So you can see micro fluidic device in silicon showing laser drilled by hole and connecting channel, so this has been done by laser beam and this channel also has been cut with the help of laser beam machining system and both are connected and they are used as a microfluidic device and dimensions you can imagine because this scale is given of 50 micron. So definitely this is around 15 to 20 micron this channel width and this is larger than maybe 200 micron size hole or so. This has been taken from this particular reference.

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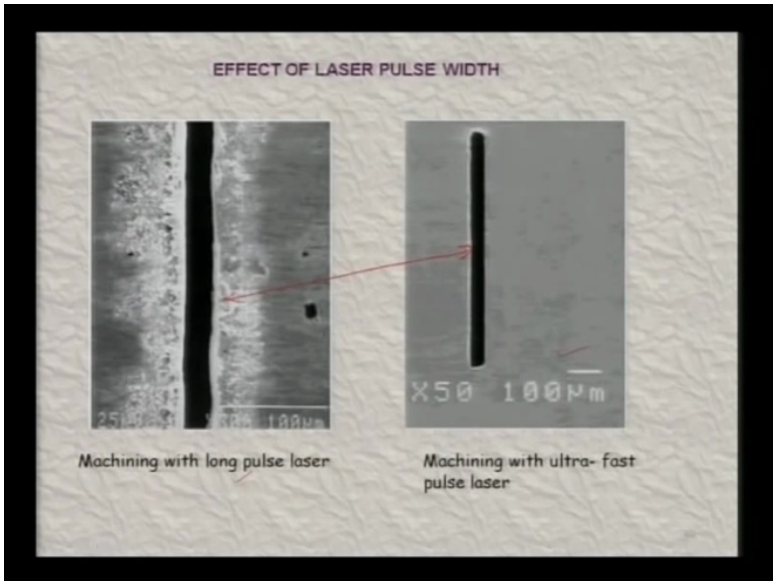

Now effects of laser pulse width, I have told you long pulses and short pulses and both affect the quality of the machine component. Now here I am going to show the effect of pulse width machining with long pulse laser, you can see the irregularity whatsoever small it may be although these are very fine very small irregularities as long as micro-machining or micro-parts are concerned but still irregularity is there when you are using the long pulses laser.

But if you use the short pulses laser you can clearly see the difference in the quality of these 2 grooves that have been made on similar kind of the work piece this is very straight and quite uniform while this is not that straight and uniform compared to the right-hand side and definitely scales are slightly different but this is with ultrafast pulse laser while it is a long pulse laser on the left side. So the type of the layer also makes a difference in the quality of the products being made.

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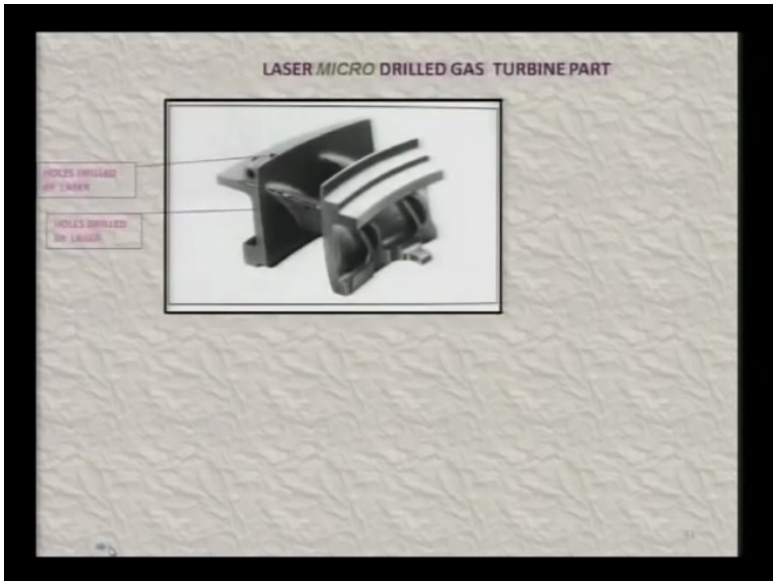

Now this is very interesting application over here as long as lasers are concerned turbine blades, laser micro-drilled gas turbine parts are there. Now this is a turbine blades are there, now all this turbine blades have thousands of which are maybe micro which may be micro-holes drilled in super alloy which are used for making these turbine blades another part of the turbine.

You can see here clearly holes drilled by the layer, very fine holes are there as you can see and these holes have been drilled in super alloy with the help of a laser beam drilling set up and there are holes which are inclined direction. Here on the other side and at the bottom also if you see there is a small hole of the top type whichever you have at the top.

Here also on the sides you have the holes and all these holes are being used for cooling the turbine blades because the temperature of these gas turbine blades is around 1100, 1200 degrees centigrade and at such a high-temperature they cannot work unless you have efficient cooling and these cooling holes are made with the help of the laser beam drilling (()) (27:08).

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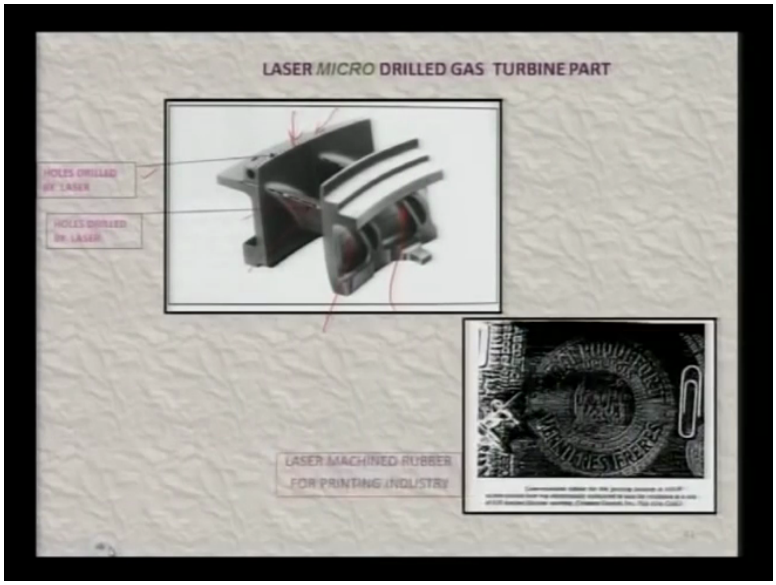

Now here is another interesting application that you know printing industries they use rubber stamps or rubber you know rubber seals kind of a thing as shown over here and it is a very complicated one and if you try to make the mould of it or by some other methods it is going to take days and days but in case of laser beam machining setup if you are able to make the part program for CNC machine then these kind of the features and these kinds of the products can be made in few minutes rather than days and once they are ready then you can use it in printing industries or textile industries wherever you have the application, so this is very pacific applications of laser beam.

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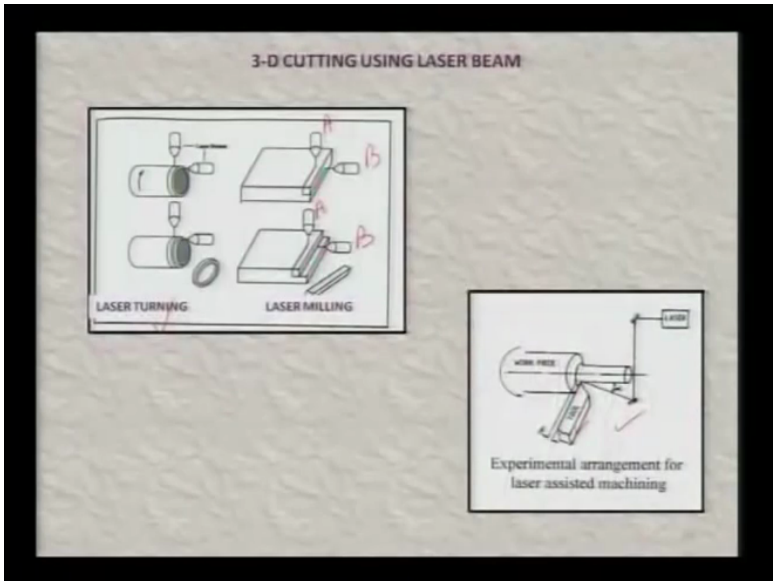

Some of the 3-D cutting I have already told you I have shown to you there are some other applications of 3-D cutting in turning operation as you can clearly see on the left inside you can perform a turning operation using 2 laser beams and gives reasonably good results and same way you can perform the milling operation again using 2 beams, beam A and beam B as shown over here in the figure.

Now such kinds of applications are good in case of very hard materials which cannot be machined by traditional methods. If you can do it by traditional methods than there is no sense in going for laser beams all other kinds of processes. Same way you can have the laser assisted machining operation as shown over here. What laser is doing over here is, that it is hitting the work piece material ahead of the cutting edge of the single point turning tool as shown over here and once it heats up the work piece material becomes quite soft and softer material can be easily cut rather than hard material. So it's become more like a hot machining using the assistance of the laser beam rather than simple plane turning and this enhances the machining rate quite considerably.

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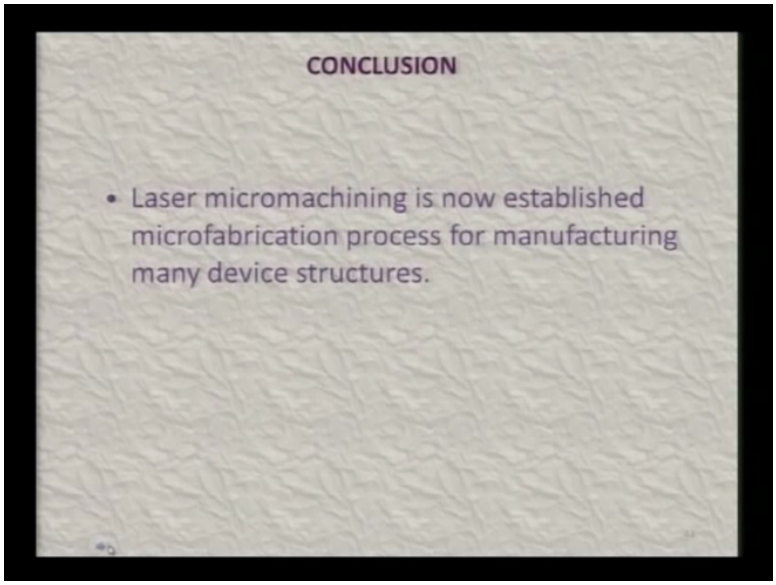

Now in conclusions, I will like to make 2 conclusions here that laser micro-machining is now established for microfabrication process for manufacturing many device structures some of the examples have shown to you at the end of the applications and with the correct choice of laser and processing parameters virtually any material can be laser micro-machined submicron procedure.

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Now here I will conclude and now Professor J Ramkumar of mechanical engineering Department IIT Kanpur will explain you one of the excimer laser setup that we have at IIT Kanpur, thank you very much.