

Manufacturing of turbines (gas, steam, hydro and wind)

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Lecture 13

Welcome to this course on manufacturing for turbines. In this lesson 13 of this course, we will look into the next machining process which is used to create film cooling holes in gas turbines. So the next machining process which is used to create film cooling holes in gas turbine is the laser beam machining. So the requirement of the film cooling holes as we have discussed previously in the gas turbine blade is to enhance the surface area so that maximum heat transfer takes place and blades can function at elevated temperature. This enables to function at a higher thermal efficiency. So these film cooling holes are generated at the periphery of the blade.

The previous process that we have seen was electric discharge machining which is also used to generate these holes but due to inherent disadvantages of presence of the recast layer as well as certain defects in the recast layer such as cracks voids and micro porosity. The alternate of laser beam machining is also used to create such film cooling holes. So, in this lecture, we will see various attributes of laser beam machining, spontaneous and stimulated emission, occurrence of laser classification, their challenges, application advantages and limitation of LBM process. So laser is basically an abbreviation of light amplification by stimulated emission of radiation.

So it is a highly collimated monochromatic and coherent light beam which is generated and focused on a small spot. So here these three terms are important to be understood. So what is meaning of each of them? So, firstly we start with collimated. So, collimated means the laser beam has the rays which are parallel to each other and this parallel characteristic of the rays is there over a very long distance. So, we can focus laser over a very long distance even then there will be no spreading.

Coherence means the laser beam can be tightly focused in a small spot, so this is the coherence of the laser. And monochromaticity means the color of the laser is a monochromatic color - a single color and because of all these characteristics we can extract very high power densities of the order of 10^6 Watt per mm square are obtained. So large variety of lasers are available in the market this include solid state laser ion laser molecular types, which can either function as continuous lasers or pulsed wave mode operation. So, here we can understand these various attributes like coherence

which is again both in space as well as time known as spatial coherence as well as temporal coherence. So, because of the spatial coherence, so we can see that the laser beam can be focused on a tight spot and temporal coherence attribute of the laser enables the fast pulsing of the laser over a narrow frequency range.

Collimated is again parallel or a long distance and monochromatic means a single color. So because of all these characteristics, so laser is a very versatile tool not only used in machining but other manufacturing processes like welding, material processing, surface texturing etc. So now we will understand how the laser beam is created by highlighting the difference between spontaneous and stimulated emission. So in any material so there are various atoms and atoms have several electrons. So these electrons generally they are available on the ground state and upon any incidence of any external photon.

So, these electrons they may gain energy. So, this external energy can be supplied using we can say the external energy is supplied using a photon in case of light or a phonon in case of heat. So, when this external energy ' $h\nu$ ' is coming in, so this electron may go from the ground state to the excited state. we can say that the difference between the energy level of the ground state is suppose E_1 and excited state is E_2 . So, E_2 minus E_1 is basically the change in energy ΔE which is supplied by the incoming photon here ' $h\nu$ '.

Now what can happen that the electron in the atom from the ground state it can go to the excited state and as any fundamental law of nature that, no material or atom or the electron wants to be in the excited state for a longer period of time. So after some time the electron may come back from the excited state to the ground state thereby emitting the same amount of energy known as ' $h\nu$ '. So, now this random movement of the electron from the excited state to the ground state is known as the spontaneous emission. So, in this case there may be several electrons doing this activity of spontaneous emission. So this means there is no sync between each of them and this is basically the spontaneous emission of radiation.

So now laser is basically an optical amplification by stimulated emission. So for stimulated emission basically we have a lasing medium. So, in lasing medium the difference between this energy level is that. So, instead of having just two levels in fact there are three levels where we have a metastable state which is just slightly below the excited state. So, we can say this third state is the metastable state.

The lower one of course is the ground state. then we of course have the excited state. So, here what is happening that again the laser because of the incoming energy ' $h\nu$ ', the atom - it goes from the ground state to the excited state, and now we have a metastable

state. Metastable state is a state which appears to be stable but it is not stable. So, here what happens, now electron may lose certain amount of energy which is a small reduction in the energy and it may come to the metastable state.

So now by doing this, the electron will of course emit some radiation in form of the spontaneous, I am denoting by SPE, spontaneous emission. Now this process can keep on continuing as long as we have an incoming energy of ' $h\nu$ '. So this process of providing the incoming or the energy for the electrons to go from the ground state to the excited state, this phenomena is known as pumping the lasing medium. So, because of this pumping action several electrons may go from the ground state to the excited state and after losing a small amount of energy by spontaneous emission, so they will come and sit on this metastable state. Now in this process, there will come a situation where the number of electrons in the ground state say N_g and number of electrons in the metastable state are more.

So, we call this situation where the number of atoms in the ground state become less than number of atoms in the metastable state. So, when this condition is achieved, we call this condition as population inversion. So because of population inversion, so what will happen? All of these electrons sitting in the metastable state, they will come back to the ground state at the same time. And when they do so, so they lose energy in sync with each other and whatever is now produced is nothing but a form of laser. So now to do this, we have this special medium known as the lasing medium.

So in the lasing medium, so it is different than any other material because it is engineered to have this metastable state which is generally absent in other mediums or other materials. So by this phenomena, so the laser is produced and this phenomena is known as the stimulated emission. So, stimulated emission is basically this phenomena where we stimulate the emission by allowing the electrons to sit at the metastable state and then come to the ground state at once. So, this is the basic phenomena how which the laser beam is produced and it is nothing but the photons which are travelling at very high speed. We can see the first occurrence of laser.

So, here it is shown the example of a carbon dioxide laser where carbon dioxide atoms they are the forming the lasing medium. So, this carbon dioxide atoms are the lasing medium and we have the pumping of the energy using this electrical discharge. So these lamps are surrounding this cavity where the lasing medium is stored so the this is the cavity where the lasing medium is stored and this may be optically transparent to this electrical discharge so maybe electrical discharge or xenon lamps may be used which provide the incoming energy for the electrons to go in the atoms to go from the ground state to the excited state. And to continue the production of laser, so the ends of this lasing cavity are flanked by two mirrors. So, on the left hand side we have the completely reflecting mirror or it is mentioned as 100 percent reflecting mirror and on the right hand

side we have a partially reflecting mirror. So completely reflecting mirror means it will reflect all the light back into the lasing medium so this continues the production of the laser as long as there is the pumping of the energy. And in the partially reflective mirror means it will allow some of the laser to pass through it to the outside and subsequently this laser beam may be used for say machining or welding or other manufacturing processes or uses. So, upon going to the excited state then entering the metastable state when there is stimulated emission the photon is emitted by all these excited atoms and this emitted photon is then transmitted by the form of laser from the partially reflecting mirror. So lasers are available in different types, different classifications are there.

So most important parameter which distinguishes the various lasers are the power. So like 1 to 5 milliwatt of the laser is used in laser pointers. And we can see that for basically creating any solid state laser, we need to have the high power lasers like 100 to 3000 Watt which are typically used in cutting operations especially in the manufacturing industry. Other than this laser is also very versatile tool in biomedical applications for various type of surgeries etc. So, here we look at the lasers which are used in industry for manufacturing processes or material processing.

So, these lasers are classified based on the type of the lasing medium. So, the type of the lasing medium it varies from solid, semiconductor, molecular, ion or neutral gas. So, in this there are various types of lasing medium which include ruby, anti-yag which is neodymium, yttria, alumina garnet, neodymium glass, then we have carbon dioxide as another molecular laser, argon based helium/neon laser etcetera. And all these lasers they also have a specific wavelength at which they are typically working as mentioned here. And all of them can be either used in the pulsed mode where we can have short time, when the laser is on and off this is known as the pulse mode and CW is basically the continuous mode, where the laser is continuously on for a relatively longer duration of time and various power levels which can be achieved by various lasers.

So now we will understand how the laser beam machining setup is placed so as the laser beam which is produced is ultimately used to machine the gas turbine blades to create the film cooling holes. So, in this setup basically we have a power source or a power supply. This power supply is there to be connected to the energy source or the xenon lamps. So, then we have the lasing medium which is surrounded by this what we can say is the flash lamps. So here the power supply is connected to them.

So here this flash lamps are surrounding the lasing medium and this lasing medium is flanked by a total reflecting mirror and the other side we have a partial reflecting mirror. So, this flash lamps they will provide the exciting energy to all the atoms electrons to go from the ground state to the excited state. And then what will happen that as the atoms they go in the excited state and they come to the metastable state upon stimulated emission, so there will be generation of the laser beam which for which we have

discussed the characteristics that it is coherent, collimated as well as monochromatic. So, this can be focused using a lens and this focus can be done on the workpiece, which is the gas turbine blade it may be creating this film cooling holes. And of course the distance between the lens and the workpiece is known as the focal length.

By adjusting the focal length, we can adjust the spot diameter, the power at that spot to have the variation in the machining performance. So, next we understand the physical processes which are occurring once the laser beam is interacting with the surface of the workpiece which is of course the gas turbine blade in this case. So, laser is basically nothing but these photons ' $h\nu$ '. So, photons which are travelling at very high speed and these photons when they come in contact with the surface of the workpiece. So, some of the photons they may be reflected and some of the photons may be absorbed by the lattice of the workpiece.

So, once they get absorbed in the lattice of the workpiece, so because of their high energy they transfer the energy to the surrounding atoms in the lattice and because of which the atoms in the workpiece they start vibrating. And because of this vibration at their main position, the temperature in the workpiece it starts to increase. So, depending on the thermal conductivity of the workpiece, so how fast the heat can be conducted, So, the temperature at the interactive zone between the laser beam and the workpiece, it starts to increase. And upon increase in temperature, so there will be change in state of the solid workpiece to liquid because as the temperature increases the material converts from solid to liquid.

And then this melting of the workpiece will continue and there may be a region of this melting separating the solid by a solid liquid interface and as there is continued exposure to the laser beam so more and more material not only melts but also starts to vaporize. Because of which material removal takes place and consequently machining is achieved so phenomenon of absorption melting and vaporization, they take place as physical processes during laser beam machining. and sometimes what may happen if we are utilizing very high power lasers so they may also form a plasma plume near the surface because very high power lasers so again it is not that hundred percent of the laser energy is always absorbed especially when once we are dealing with the metallic surfaces which are quite reflective so this presence of this plasma may further reduce the process efficiency So, proper care needs to be taken to process the surface such that the maximum absorption of the laser energy takes place. So this challenge in laser beam machining, so as we just talked about the reflectivity of the material is one of the main challenge which lowers the material removal rate. And in case of metals, they mostly reflect 90% of the incident radiation at low power densities.

So reflectivity level can be substantially reduced by changing the surface characteristics such as by introducing various textures. and unreflected light may then be absorbed

which raises the metals to the high energy state, the electrons which are present in the metal. Energy absorbed by the electrons is rapidly then passed to the lattice and sufficient heat is generated which starts to melt and evaporate the piece. So, here we can see the cutting speed of various materials which can be machined using laser beam machining.

And all these materials which are non-metallic they can be machined at much higher speeds and all the metals as shown here they are able to machine at a slower speed because of the challenge of reflectivity then if we put the machinability rating that is how easily we can machine a given material so in this case we can see the machinability rating of the super alloys which are used to make the gas turbine blades is relatively less but nevertheless laser has been a very versatile tool to create the film cooling holes. Other materials like gold, silver or titanium based alloys they have high machinability rating with respect to laser but our focus here is on the nickel based super alloys which have relatively low machinability rating. So we can say typical applications of laser is to machine difficult to cut materials, especially the high strength, thermally resistant alloys, various kinds of carbides, fiber-enforced composites, stellites and ceramics. Laser beam machining also offers good solution that is indeed more associated with material properties such as thermal conductivity, specific heat, as well as melting and boiling. Lasers are widely used in various industrial applications for plating, heat treatment, cladding, alloying, welding and machining.

So here we can see other applications of lasers, which include dressing of grinding wheels, laser milling, fine-cutting. And by the capability of focusing and defocusing the laser beam on a tight spot, the same laser beam can produce holes of the order of, say, 13.5 micron in a sheet of 1.2 millimeter thickness. And by focusing it on a further tight spot, it can be brought down to 6 micron in a sheet of 0.03 millimeters.

So here we can see some other examples of parts which are produced using laser fine cutting as shown here. So we can summarize the advantages of laser beam machining which has minimum tool wear and breakage. Holes can be located accurately by using optical laser system. Small holes with large aspect ratio can be produced. All materials which are difficult to cut have high strength can be machined and machining is done very rapidly and setup times are quite economical. Laser can also be used to drill hole at difficult entrance angles. And because of the flexibility of the process, this process can be easily automated and the operating cost is low for this process. But the process also has certain limitations because lasers are known to have very high cost.

So the high capital cost of the equipment is one of the limitation and sometimes there may be tapers encountered in direct drilling of holes because as that aspect ratio increases, the workpiece material may be conducting more heat, so ultimately we may observe some taper. Blind hole with precise depth may be difficult to achieve and thickness is restricted to 50 millimeter at optimum conditions. And at times there may be

some adherent material sticking to the exit of the holes which needs to be removed by subsequent processing. So, in summary of today's lecture, we have looked at the application of laser beam machining to machine the film cooling holes in gas turbine blades. We have understood the mechanism of laser beam generation that is the stimulated emission.

We have also understood the setup details of laser beam machining. We have looked at the physical processes that take place when a laser interacts with workpiece. and lastly we have seen other details such as advantages limitations and applications of laser beam machine. So in the next lecture we will look at the finishing processes which are used for gas turbine blades in which one process is very pertinent, this is the creep feed grinding. So, details of creep feed grinding will be looked in the next lesson.

Thank you.