

Laser Based Manufacturing

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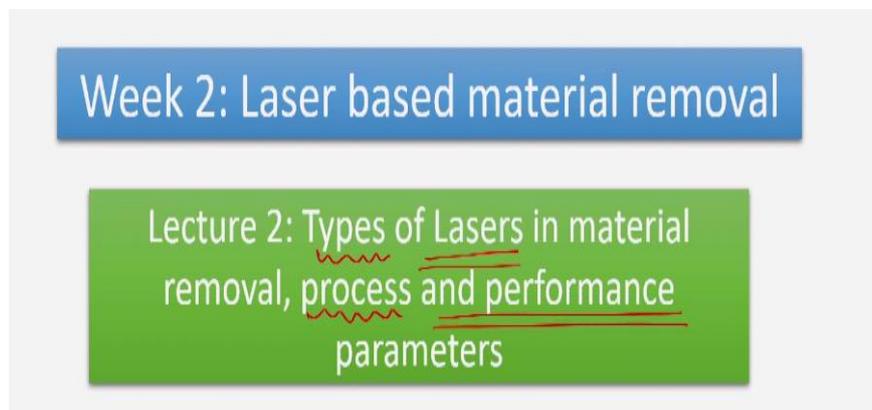
Module # 02

Lecture # 05

Types of Lasers in Material Removal Process and Performance Parameters

Hello everyone. I welcome you all to the Lecture 2 of Week 2 of NPTEL MOOC course on Laser Based Manufacturing. In our previous lecture, we have seen the material removal by using lasers. In this lecture, we will be learning about what are the various types of lasers which are used in the laser based material removal and we will also see what are the various process parameters, performance parameters and how the process parameters are affecting on the performance parameters, that is the product quality and the productivity. Let us begin our lecture.

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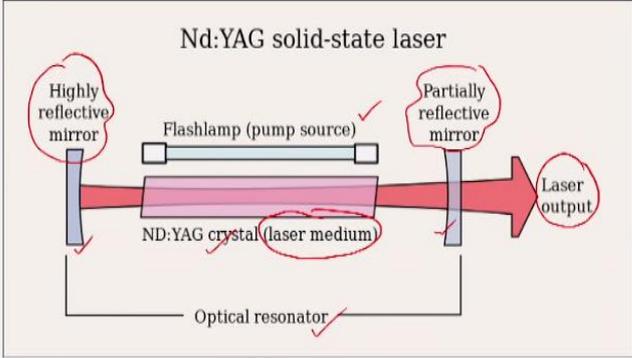
These are the types as I mentioned, the types of lasers. In particular we will be studying today two types of lasers: the first one is the Nd:YAG laser and the second one is the CO₂ laser that is the gas laser. Process parameters and performance parameters will be studied in detail and their interaction, that we will also see.

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Let us begin our discussion on the types of lasers which are used in the material removal operation. In our previous class we have seen that there are basically three modes in which the lasers can be utilized in the material removal operation that is the flame cutting, the fusion cutting and the remote cutting. For all these processes basically three types of lasers in the view of the lasing mediums are used that is the solid-state laser, liquid state laser and the gaseous lasers.

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Nd: YAG Solid-State laser

<<https://commons.wikimedia.org/wiki/File:Laseroons.svg>>

- The smaller thermal load by Nd:YAG laser allows the machining of some brittle materials such as SiC ceramics without crack damage.
- Due to shorter wavelength, Nd:YAG laser is highly absorbed when falling even on a reflective surface.

- Neodymium-doped Yttrium Aluminium Garnet
- Laser generally generated commonly in the near-infrared region of the spectrum at 1064 nm
- Both pulsed and continuous mode
- Although the mean beam power is relatively low, the beam intensity can be relatively high due to smaller pulse duration and better focusing behaviour.
- Smaller kerf width, micro-size holes, narrower heat affected zone (HAZ) and better cut edge kerf profile can be obtained in Nd:YAG laser beam machining.

The first laser which is very commonly used in the industry is the Nd:YAG solid state laser. It is a solid state, means the lasing medium is in solid form. The acronym Nd:YAG is used for word that is neodymium doped yttrium aluminum garnet. Here neodymium element has been doped into yttrium aluminum garnet and this solid is being used to generate the laser beam in the manufacturing operations.

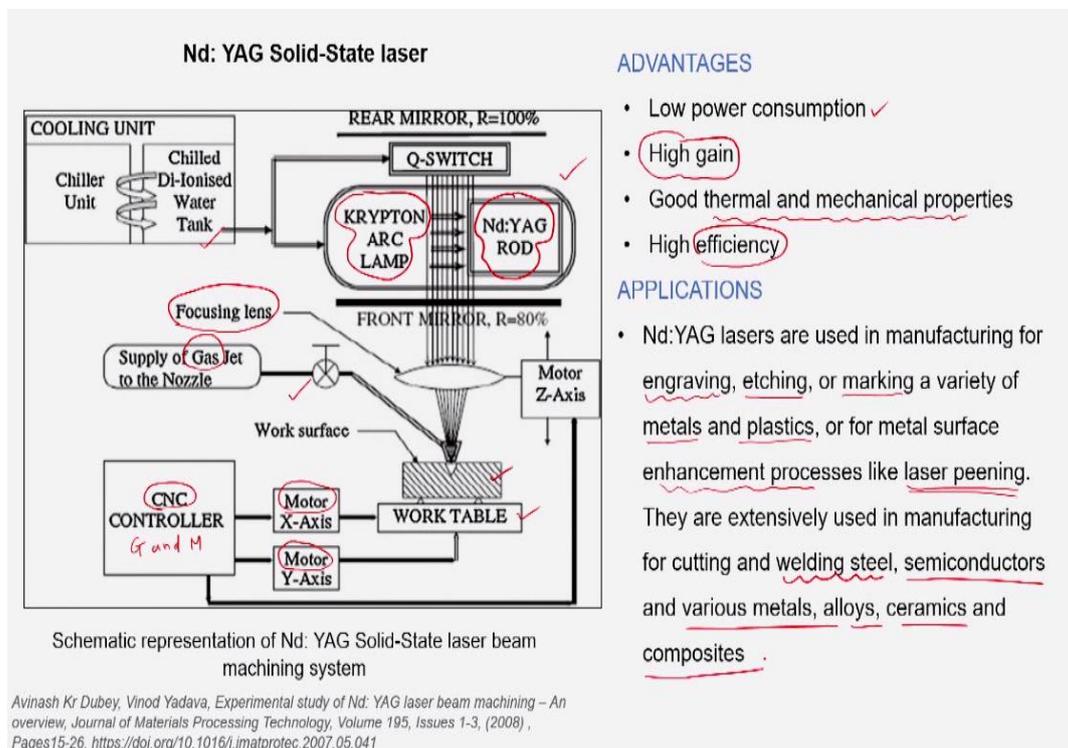
This laser falls into the near infrared region and it provides the wavelength of about 1,064 nanometers. This laser is also used in both the form that is pulse mode and the continuous mode.

Now, let us look at the construction of Nd YAG solid state laser. Here we are having the laser medium. This is the laser medium that is the Nd:YAG crystal. We are having the excitation source that is flash lamp a pair of mirrors. First mirror as we know is a very highly reflective mirror and the second one is the partially reflective mirror and through which we are getting the laser output. This entire assembly is called as optical resonator that we have already seen in our previous class. Although, the mean beam power in Nd:YAG laser is relatively low. The beam intensity can be relatively high. In this case we can have a high intensity of the laser

beam by having small pulse duration. If you reduce the pulse duration we can increase the beam intensity at a higher scale although the beam power is less and we can have a better focusing behaviour as well by using this kind of lasers. When we are putting up the small pulse duration we can achieve smaller kerf width, microsized holes can be machined by using this Nd:YAG laser and it is generating a smaller or narrower heat affected zone. We will see what is the meaning of heat affected zone in our next slides.

Now, this laser thermal load or smaller thermal load is very much helping to process the brittle materials. As we know that brittle materials if we apply the energy to them there maybe chances of having the damage due to the cracks. These can be solved by using applying the smaller thermal load and that is possible by using this Nd:YAG lasers. Nd:YAG lasers are also providing the shorter wavelengths and that is helping us to get more absorption of the laser beam by the surface of the work material and that is an added advantage when we process with the Nd:YAG based solid-state laser.

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Now on your screen you can see one more arrangement of these Nd:YAG solid state laser. Here you can see there is the Nd:YAG rod, that is a solid state rod and there is an arc lamp. This is the krypton arc lamp. This lamp is applying the photo energy to the Nd:YAG rod and this Nd:YAG rod is generating the laser beam. The generated laser beam is focused on the workpart. This is the work part which is mounted on the work table. The focusing of the laser beam on the work part is carried out by using a focusing lens. This is the focusing lens. The workpart which is mounted on work table is maneuvered or it is operated or translated in XY direction by using two motors - motor for X axis and motor for Y axis and these two motors are being controlled by a CNC controller.

To have the simultaneous motions of this X axis and Y axis we have to write G and M code, the CNC part program. Now in our previous class we have seen that we are putting up some inert gas - the gas is used to carry away the molten material and to protect the finished edge or finished surface during the work operation. There is a nozzle through which we are applying the inert gas.

Now, when we apply a very high arc lamp intense radiations on the Nd:YAG rod. The temperature of the entire system would be very high. To cool down the temperature, to control the temperature of entire system we are using chilled de-ionised water tank: this is an heat exchanger and that heat exchanger is using to control the temperature of the entire system so that we can work in a safe mode.

The advantage of Nd:YAG laser is that it consumes low power, the power consumption is low, the gain of the Nd:YAG laser is quite high. We are getting high gain during the population inversion and we can achieve very good mechanical and thermal properties during the operation. The efficiency of the laser operation is also quite high.

What are the various applications that are there in the manufacturing? Nd:YAG is quite widely used for engraving, etching, marking for variety of metals, plastics. Moreover, the Nd:YAG lasers are also used for the enhancement processes such as the laser peening. Here the laser peening is the surface modification technique where we are modifying the surface texture by indenting, by applying certain plasma wave generated by the lasers. Nd:YAG is also using in welding of the steels and processing the semi-conductors and variety of materials such as alloys, ceramics and composites.

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CO₂ Laser

AC or RF power unit

Cathode Anode

Lasing medium

CO₂ Na He

>99.5% 35-60%

Gas CO₂ Laser

Shigeru23, <https://commons.wikimedia.org/wiki/File:CO2_Laser_model_%28simple_side_view%29_En.svg>

- CO₂ molecules act as an active or laser medium and N₂ molecules help in achieving the population inversion.
- Electric current -> nitrogen molecules in the gas mixture become excited -> gain energy.
- Nitrogen -> it can hold this excited state for long periods of time without discharging the energy in the form of photons, or light. If you excite nitrogen, it can then transfer its energy surplus to neighbouring CO₂ molecules.
- The high-energy vibrations of the nitrogen excite the carbon dioxide molecules -> population inversion.
- CO₂ molecules lose their excited state by releasing energy in the form of photons. => Laser Beam
- Typical gas mixtures have an N₂:CO₂:He ratio of 1:1:8.

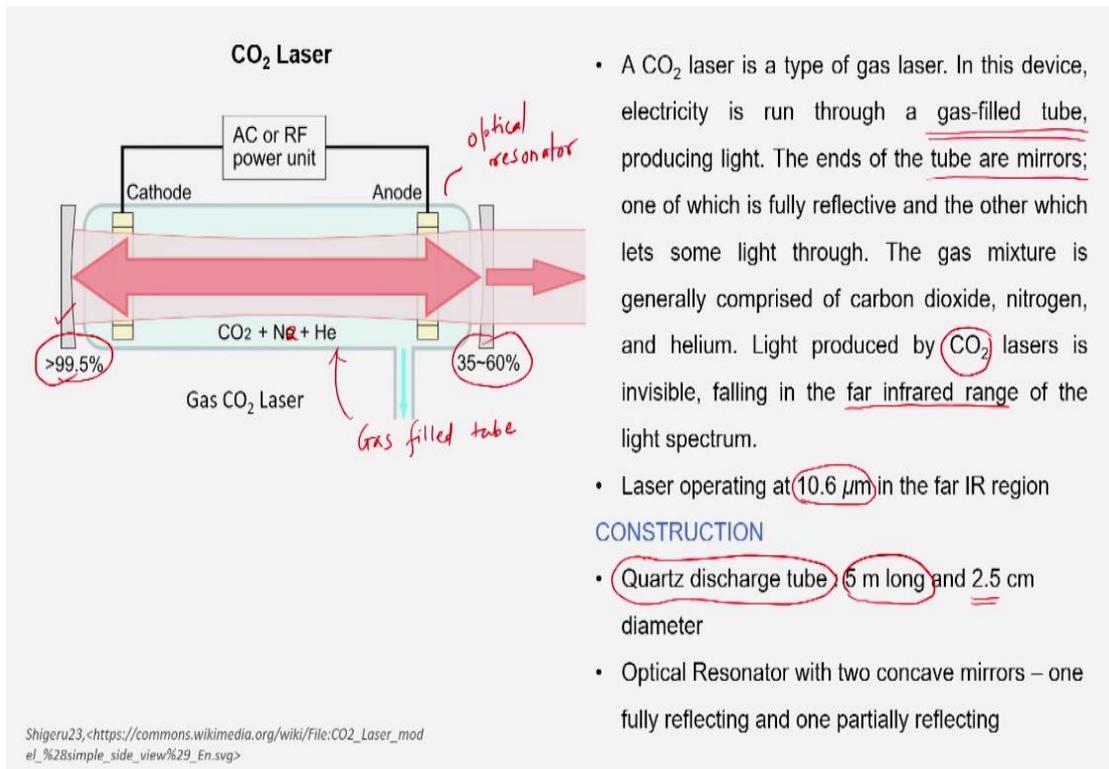
Now, let us look at the second type of widely used laser that is the carbon dioxide laser, is a gas laser basically, it is a CO₂ laser. The schematic of the CO₂ laser is there on your screen. You can see, we are having a tube and inside the tube we are putting up a mixture of gases and these gases are CO₂ - that is a carbon dioxide, then we are having nitrogen and helium. This is nitrogen and helium are put or mixed along with the CO₂ to get the required CO₂ laser.

We are applying the electrical field inside this lasing medium. This is gaseous based lasing medium that we do have. The CO₂ laser has a tube and the tube has a mixture of carbon dioxide, nitrogen and helium and we are applying the electrical field across this tube. When we apply electrical field the population inversion will occur and we are getting the laser beam through this partially reflected mirror.

Now, let us see the significance of variety of its constituting gas elements. CO₂ is basically the lasing medium. It is contributing to get the required laser pulse, then what is the use of N₂ that is the nitrogen? Nitrogen is helping to achieve the required population inversion. Now, how it is possible? When we apply the electrical current or electric field, these nitrogen molecules in the gas are getting excited. They are gaining energy from this external source electrical field. The peculiarity of nitrogen is that, it can hold this excited state for long period of time without discharging the energy in the form of photons. The metastate of the nitrogen is quite long. The nitrogen can hold the excited state for longer period of time. Due to this we can get certain stability at the time of population inversion. Now, when these nitrogen atoms are at the excited levels, they are vibrating and these vibrations or the surplus excitation energy will be transferred to the neighboring CO₂ molecules. Surplus energy which is there with the nitrogen will transfer to the CO₂ atoms and this CO₂ molecules then get excited, but the metastate or the excitation state for the CO₂ is not that long in comparison with the nitrogen. Naturally the CO₂ molecules will decay, they will come to the ground state through the intermediate states and during the decaying operation they are releasing the photons. CO₂ is generating the photons and the nitrogen is helping to get the required population inversion.

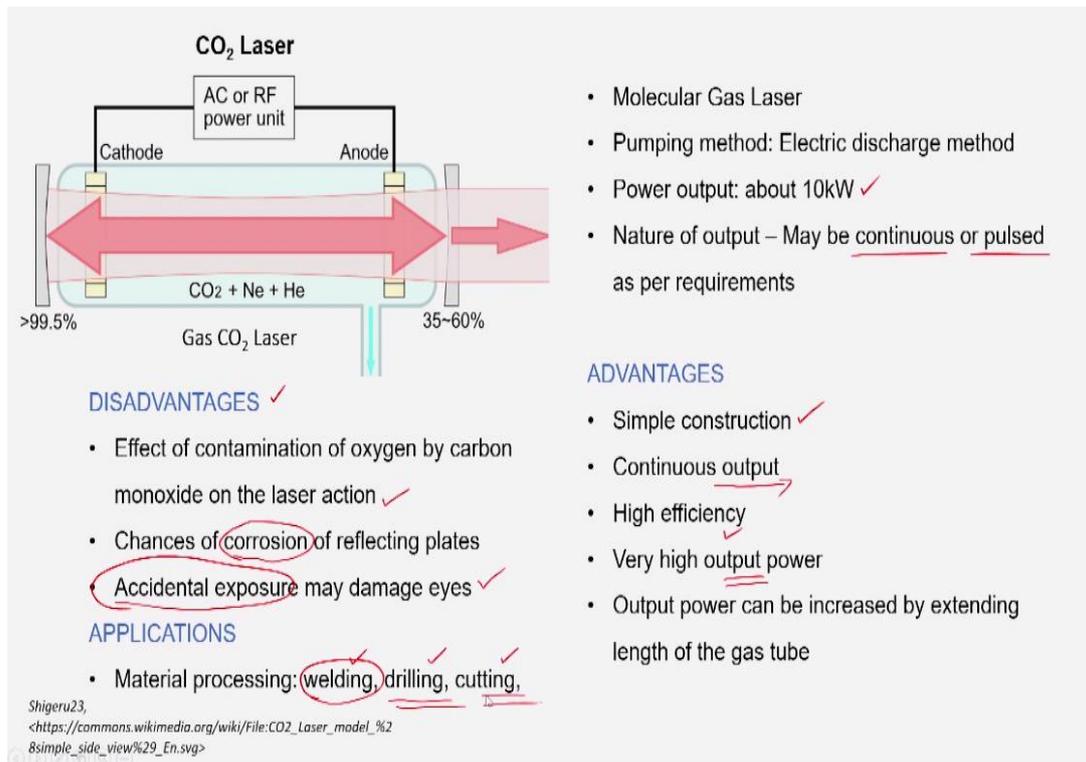
When the CO₂ molecules they come down to the ground state they are releasing the photons and that photons are generating the laser beam. Now, when these CO₂ molecules comes to the ground state, some energy will be there with them and that remaining energy will be given to the helium gas and that is called as the relaxation process. The extra energy or the residual energy with the CO₂ molecules will be given to the helium. Now, if you look at the gas mixture you can note that the nitrogen and carbon dioxide, they are having almost equal proportion inside the mixture and the majority is the relaxation gas that is the helium.

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Fine. This is the typical construction of CO₂ laser. It is having a gas filled tube. This is the gas filled tube and the tube is accompanied with set of mirrors. This is one mirror which is completely reflective, reflectivity is very high and the second mirror is partially reflective. The laser which are generated by the CO₂, they are following in far infrared range. It is about 10.6 micro meter is the wavelength of the laser beam that is produced by using the CO₂ gas. To construct the CO₂ based laser we need a quartz-based discharge tube and in general it is of length of 5 meters long and it is having about 2.5 centimeter of the diameter and this entire assembly that we call the optical resonator. This is the optical resonator. We have already seen its details in our previous week lectures.

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Well, the general details about the CO₂ lasers are in front of you. The maximum power output can be achieved is about 10 kilowatt. The CO₂ lasers are producing the beam in continuous as well as pulsed mode as per our requirements.

There are various advantages associated with the CO₂ laser. The first is the construction is simple, we are getting continuous output which is required for the continuous cutting in material removal processes. The efficiency in comparison with other lasers is high and we are getting very high output lasers. Therefore, it is very popular in heavy industry laser-based processing. However, there are certain disadvantages. There may be effect of contamination of oxygen by the carbon monoxide during the laser action: this is one problem or limitation of the CO₂ laser. There are chances of corrosion as well in the reflective plates during this CO₂ based lasers.

Since, the power generated by the CO₂ laser is quite high: they are dangerous and they may damage to your eyes in the accidental exposure. Basically if we are getting the laser on the human beings in the eyes or other body parts it may damage. The obvious applications are welding, drilling and cutting in laser based material removal or manufacturing processes. Of course, the welding is the joining process. But drilling and cutting are the material removal process where we are using the CO₂ based lasers.

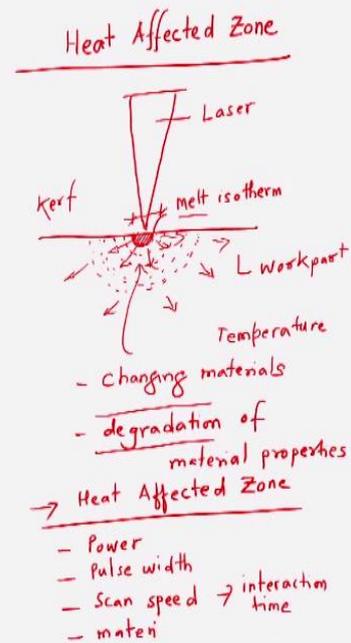
Now, let us see what are the various process parameters used in the laser-based material removal. This topic is of very much importance and of interest to all the research community those who are working in advanced manufacturing technology.

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PROCESS PARAMETERS OF LASER-BASED MATERIAL REMOVAL

LBM is an advanced manufacturing technology: very useful and important; however requires high capital investment and has low efficiency. Therefore it is essential for better utilization of resources, the levels process parameters are to be optimum. This will certainly help in achieving the desired process performance in terms of product quality and productivity.

Product quality: geometrical accuracy, surface roughness, heat affected zone, recast layer, etc.



The reason is quite obvious. There are numerous advantages of lasers in manufacturing. However, there are certain basic limitations of laser. The capital investment of the laser is quite high that is the first point and the second point is the efficiency of the laser is quite low in comparison with other manufacturing processes. Therefore, it is very natural that all the researchers and the engineers across the world are focusing their attention to find out the right level or the optimal level of process parameters which are affecting the process performance.

As far as the process performance of the laser is concerned: there are two basic things that is the product quality and the productivity. Product quality of the laser based components is having the geometrical accuracy - the edges of the laser cut parts; then the heat affected zone which is another important aspect as far as the laser beam processing is concerned. Then the dross or the recast layer or the deposition of molten material on the cut surface is also another important aspect as far as laser based processing.

There are lot of efforts are being done at Master levels or PhD level in all the universities across the globe to use variety of lasers on variety of materials and try to find out the effect of process parameters on this. Even industry is working on this and try to find out the optimal level so that the productivity can be enhanced.

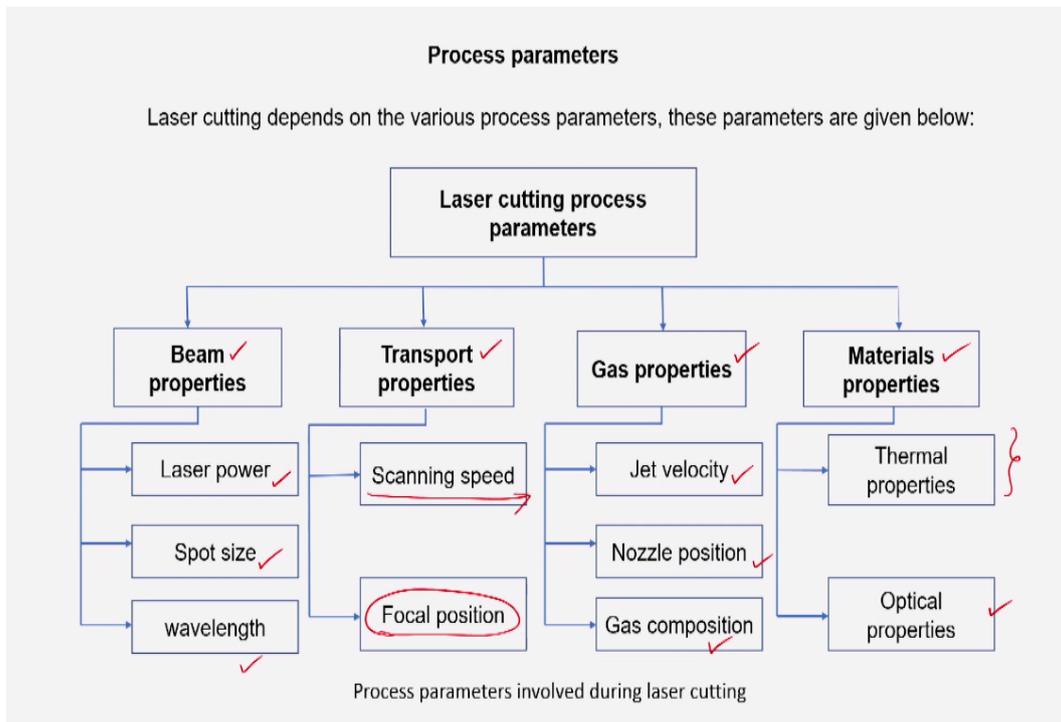
Now, there is important factor as I mentioned that we call heat affected zone. What is the meaning of heat affected zone? In our previous class we have seen that the laser beam is being applied on the workpart and then there is a melting and evaporation will occur. These are the isotherms and let us consider that this is the melt isotherm. This is laser and this is the workpart. During the application of laser on the surface, we have got the temperature curve which we called the isotherms. At the melting point we got certain area, certain volume which is

considered to be removed or melted and afterwards by using the inert gas it will be removed. Based on this we can find out the width of the laser cut and that width of that laser cut it is called as kerf. But what is happening, the temperature at this point is much above the room temperature and it is at the melt point temperature still there is conduction of heat inside the work material.

And due to increase in heat, increase in temperature inside the work material there is degradation of the material properties and the degradation maybe in few microns or few millimeters inside the work material, that all depends upon the thermal conductivity of the work material, the power that we are applying on the workpart and the duration for which we are applying the power - that is the density. Density and the thermal conductivity both are affecting the generation of the temperature.

Now, when we say that there is a huge temperature being generated at the laser material interaction, certain harsh temperature will also be there around the laser spot and that harsh temperature or the excess temperature is changing the properties of the work material, changing the material properties or some people are calling that the degradation of the material properties. And the zone in which the material properties are degraded that is called as the heat affected zone. This is the part of parent material where the material properties are degraded that is called as heat affected zone. When such part which is thermally affected is used for some critical application or precision application; during that fatigue based operation or the heavy operation where endurance strength is required, a small crack on the surface may lead to the disaster. Small crack may get propagated and the component may get failed. This heat affected zone is to be very carefully studied and there should not be any thermal stresses which are generated more than the yield point stress. This heat affected zone has to be studied very carefully, the thermal stresses which are generated in the heat affected zone must be carefully understood and the process parameter should be modulated, the process parameter should be tuned in such a way that these thermal stresses should be in a control and that control is through reduction in the heat affected zone. This heat affected zone is controlled by using power, pulse-width - that is interaction time, the scan speed - that is interaction time and the material properties - that is conductivity.

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Now, let us see the detail classification of the process parameters, which are used in LBM that is laser based machining or the material removal. This process parameters are broadly classified into four categories; that is beam properties, transport properties, gas properties and material properties.

What are the various beam properties which are used? laser power, the spot size and wavelength of the laser: laser power in watt that we consider, the power that we apply during the lasing action that is the laser power, spot size is the diameter or the size of the spot at the surface wherever the laser is being applied that is the spot size and wavelength of the laser.

As far as the transport properties are concerned, the scanning speed which is controlling the interaction time of the laser with the materials that is scanning speed. Focal position the second parameter related to the transport properties. As far as the gas properties are concerned the velocity of the inert gas - the velocity of the jet of the inert gas that is the first gas property which is affecting the performance. Position of the nozzle with respect to the work part or the feature on which we are applying the laser beam, composition of the gas what kind of gas you are using either you are using inert gas or you are using some sort of the gas which is helping for more energy input that is oxygen.

The thermal property that is the thermal conductivity is again a very important parameter during the laser beam processing. If the thermal conductivity is less, then the local temperature would be very high and when the local temperature is high: there would be more melting at the localized spot and there may be vaporization as well. If the thermal conductivity is high the local temperature would be less and we may have a wider kerf or we may have you can say shallow craters due to the laser beam.

Optical properties if the material surface or the work part is reflective which is happening in the case of the aluminum; that reflective surfaces are not good for the laser processing. Reflectivity or the absorptivity is an important parameter.

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| Sr. no. | Quality characteristics | Significant factors | Variation of factors to keep minimum value of quality characteristics | Sr. no. | Quality characteristics | Significant factors | Variation of factors to keep minimum value of quality characteristics |
|---------|-------------------------|------------------------------|---|---------|-------------------------|-----------------------------------|---|
| 1. | HAZ | Beam energy ¹ | Low ✓ | 2. | Taper | Beam energy ¹ | Low ✓ |
| | | Feed rate ¹ | High | | | Feed rate ² | High ✓ |
| | | Pulse duration ² | High ✓ | | | Pulse frequency ² | Low ✓ |
| | | Pulse frequency ² | Moderate ✓ | | | Pulse duration | High ✓ |
| | | Gas pressure | More | | | Material thickness ^{1,3} | More |
| | | Material thickness | Low | | | Focus position ³ | Above the work surface |

Avanish Kr. Dubey, Vinod Yadava, Experimental study of Nd:YAG laser beam machining—An overview, Journal of Materials Processing Technology, Volume 195, Issues 1–3, 2008, Pages 15-26.

Now, let us look at what are the quality characteristics which are considered and what are the various significant factors which are affecting on that quality characteristics and what should be the variation in these factors to keep the quality characteristics at its lower value. As we have seen that HAZ heat affected zone and it has to be at its lower level or it has to be at its lower value. What are the various process parameters that we can modulate or we can change: these are beam energy - that is the laser beam energy, power, feed rate that is the scan speed, pulse duration that is the time for which we are applying the laser beam, frequency of the pulse, how many number of pulses that we are applying per second, pressure of the gas (inert gas) which we are using during the cutting operation and the thickness.

To have the HAZ value at its lower level we need to have the smaller laser beam energy. It is very natural if the power is less: the heat affected zone would be low. Feed rate that is the interaction time; it can be reduced by having higher scan speed or higher feed rates so that the interaction time would be low and HAZ would be low. Pulse duration can be high if duration of the pulse is high then the density would be low and heat affected zone maybe low. Pulse

frequency maybe the moderate level and we can have more gas pressure so that the molten material has to be flushed away, the molten material has to be taken away from the site of its generation so that this molten material will not dissipate/will not conduct more amount of heat inside the substrate material. As soon as we are melting the material it has to be removed. The thickness has to be low. If more thickness is there, naturally the heat affected zone would be more.

Then we are facing the problem during the laser cutting is the taper that we get. In our previous class we have seen that the taper is not desired, not expected. Again the same set of factors we can consider. When the beam energy is low we are getting low taper - naturally the energy is low so the taper would be less. Feed rate is high - interaction time should be low: Frequency has to be low: here the peculiar thing if the frequency is low that means the number of pulses per second would be less and we can have the uniform dissipation of heat along the Z direction along the depth. That is why the frequency is recommended to be low. Duration of the pulse is recommended high and the thickness of the material should be more. That more material is available for the metal cutting operation we can get comparatively or relatively less taper.

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| Sr. no. | Quality characteristics | Significant factors | Variation of factors to keep minimum value of quality characteristics | Sr. no. | Quality characteristics | Significant factors | Variation of factors to keep minimum value of quality characteristics |
|---------|-------------------------|------------------------------|---|---------|-------------------------|---------------------------------|---|
| 3. | Surface roughness | Beam energy ¹ | Moderate ✓ | 4. | Recast layer | Beam energy | High ✓ |
| | | Feed rate ¹ | Moderate | | | Pulse duration ^{1,2} | Low ✓ |
| | | Pulse frequency ¹ | Moderate | | | Gas pressure | High ✓ |
| | | Gas type ² | Inert | | | Material thickness ¹ | Low |
| | | Gas pressure ² | Moderate | | | Focus position ² | Above the work surface |

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Then there is another surface or product quality factor that is the surface roughness. Again, look at the various factors which are affecting the surface roughness. To have the controlled or good quality surface during the laser beam operation we are using moderate level of beam energy, feed rate and pulse frequency. The roughness can be achieved at its desired level by having the moderate level/medium level of the beam energy, feed rate and pulse frequency - it should not be too low or too high. And certainly, we should have the inert gas, the oxygen

should not there so that the oxidation will not be there of the generated surface, the inert gas has to be applied. Pressure has to be again at the moderate level.

As far as the recast layer is concerned or the deposition is concerned let us see what is the effect of various significant factors. If beam energy is high, we are getting low recast layer because there is more vaporization than the melting. It is expected that more material has to be vaporized, evaporated. If there is more melting then there would be more deposition. Pulse duration should be low so that we can generate high density of laser power. The pressure of the gas should be very high so that whatever the material removal which is there due to the melting because melting we cannot avoid, some portion is vaporized and some portion is melted. The remaining portion or the portion which is melted has to be completely removed by using the inert gas flow. Material thickness has to be low if more material is there naturally more deposition or recast layer would happen.

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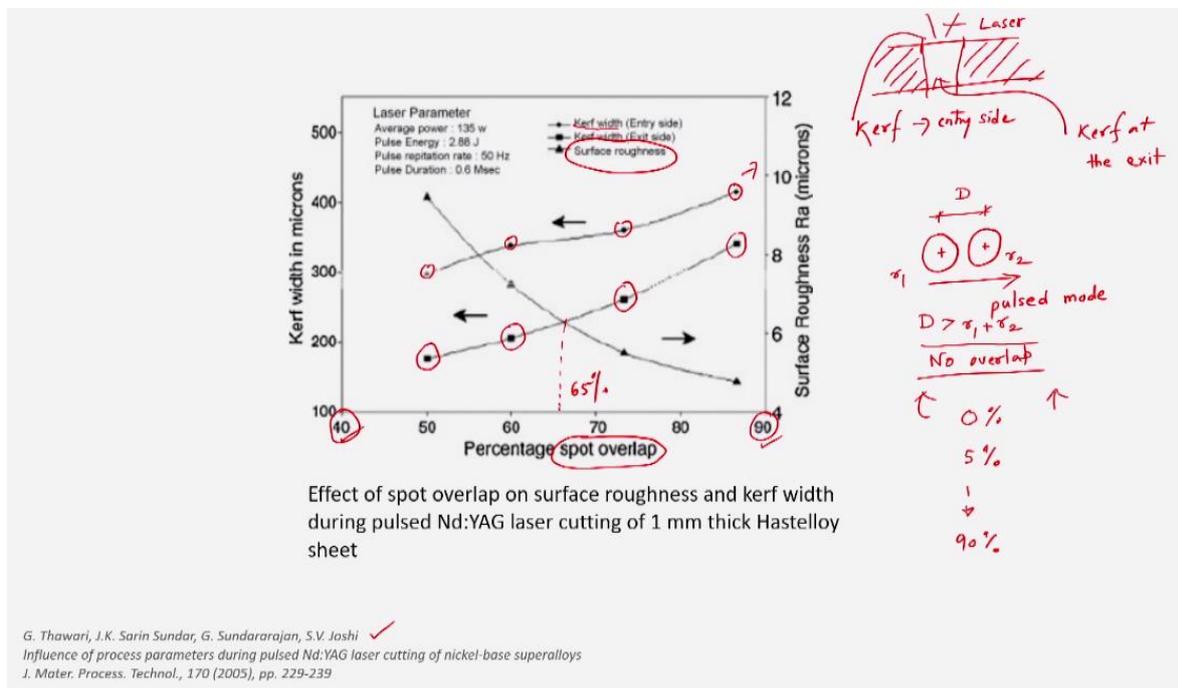
| Sr. no. | Quality characteristics | Significant factors | Variation of factors to keep minimum value of quality characteristics | Sr. no. | Quality characteristics | Significant factors | Variation of factors to keep minimum value of quality characteristics |
|---------|-------------------------|------------------------------|---|---------|-------------------------|------------------------------|---|
| 5. | Dross adherence | Gas type ¹ | Inert | | | Pulse frequency ² | Low |
| | | Gas pressure ¹ | High ✓ | | | | |
| | | Beam energy | High ✓ | | | | |
| | | Feed rate ² | High ✓ | | | | |
| | | Pulse frequency ² | Low | | | | |
| 6. | Micro-cracks | Beam energy | High ✓ | | | Pulse width | Low ✓ |
| | | Gas pressure ¹ | High ✓ | | | Gas type ¹ | Inert |
| | | | | | | | |
| | | | | | | | |

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Dross as we have seen that there is a rich formation at the entry of the laser beam, some deposited material would be there at the entry of the laser beam, at the entry of the laser cavity, drilled cavity. To avoid this dross adherence during the laser-based processing we have to use the inert gas; we should not use oxygen. Then we are using high gas pressure, high beam energy and high feed rate during these operations. And the pulse frequency has to be low. When we are applying high pressure gas then the dross will be removed at the time of its deposition only. If the beam energy is high then the dross will not be generated because it may get vaporized, lesser amount would be melted and that would be removed by applying the high gas pressure. When the feed rate high, then also we are having lesser interaction time and due to that less interaction time the dross will not be stayed for a longer duration on the surface.

Now, cracks or the micro cracks as I mentioned when this laser-based components are used in high fatigue applications where the endurance strength has to be high. The cracks are very dangerous during such applications. The laser processed parts are to be examined for the micro cracks, but micro cracks can be minimized, they can be controlled at the time of their manufacturing. How can we have the lesser micro cracks? You can reduce the pulse frequency, you can have the high beam energy, the width of the pulse should be low, the gas pressure can be high and it should be the inert gas pressure. To minimize the HAZ; whatever the parameters which we are using for the heat affected zone, the same set of parameters can be utilized to reduce the possibility of micro cracks during laser beam operations.

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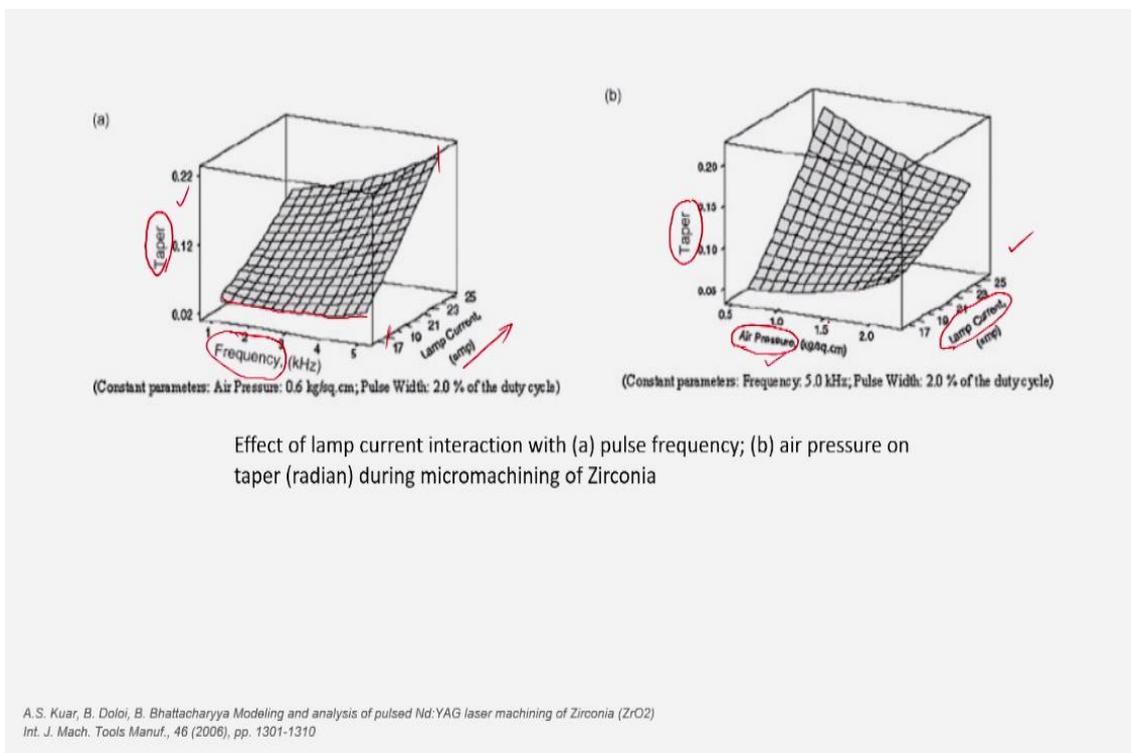
Now, there is another interesting process parameter that we call the spot overlap. The spot overlap is also affecting the width of the kerf, the quality of the laser processed material. What is the meaning of the spot overlap? Let us consider we are using a pulse laser. This is the first spot that we got and now we are moving the laser in this direction in pulse mode, this is a pulse mode. Now, if I am having another laser at this spot. Now distance between the center of these two spots. This is the distance; if this distance is more than the addition of these two radii: radius 1 of spot 1 and radius 2 of spot 2. If I say that if D is more than $r_1 + r_2$, there is no overlap.

But you consider that we want to have the deliberate overlap of the second pulse over the first pulse to get some channel. What should be the optimum overlap between the pulse 1 and pulse 2? It should not be of the same time. Here what we consider? that there is a pulse overlap of about 40% to 90%. What is the effect of this spot overlap? Now in this case it is 0. This is a 0% in the above case. It can be enhanced, it can be say 5% up to 90%. Here we are using a 40% minimum and the 90% minimum. The experiments have been carried out by the researchers which are mentioned over here. And what they noted that when we increase the

pulse overlap or the spot overlap? This is the kerf width which is increasing. It is expected that the pulses should get overlapped with each other so that we can get wider kerf width. Now, we can have the kerf width at both the ends. If suppose this is a metal sheet that we do have and we are applying the laser over here. This is the laser. We can have the kerf width at the entry. This is called as kerf at the laser entry side and this is the kerf at the exit. Now both the parameters have been studied and it has been noted that when the percentage spot overlap is increasing then we are getting wider kerfs both at the entry and exit.

However, it has been noted that the roughness is getting reduced. With percentage spot overlap increasing there is better surface quality that we are getting, but the width is also getting widened up. Here you can say there is multi output optimization, how much optimum number of spot overlap should be there to get the required thing. There is a trade-off here. Suppose you want moderate level of the kerf width and good quality surface finish you can have about 65% of the spot overlap.

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There is another case here and this case is about the lamp current or the energy that we are putting up and the frequency of laser application and the process parameters or the performance parameter which is studied here is the taper. What we notice here? when we increase the lamp current, when we increase the applied energy, the taper is also getting increased. However, for constant low level of lamp current, so, you can see that with increase in frequency the taper is not that much increasing, the taper is having the horizontal relationship, there is no significant enhancement in the taper when we increase the frequency at low level of lamp current. However if we increase the lamp current then there is increase in taper. This is a good indication that how much should be the optimum level of lamp current to get the required taper.

There is another case here: and in this case we are using the variation of lamp current along with the air pressure that is the gas pressure on the taper or the quality of the laser drill. Here you can see as we increase the current, as we increase the power taper is increasing. As far as the air pressure is concerned for low value of laser current there is not much increase in the taper even though we are increasing the air pressure.

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POWER

- By increasing laser power, cutting depth and width increases ✓
- High power usage leads to metallurgical defects → High HAZ → defects, micro-cracks

SPOT SIZE ✓

- Most important for machining operation
- Decrement in spot size increases laser power density

WAVELENGTH

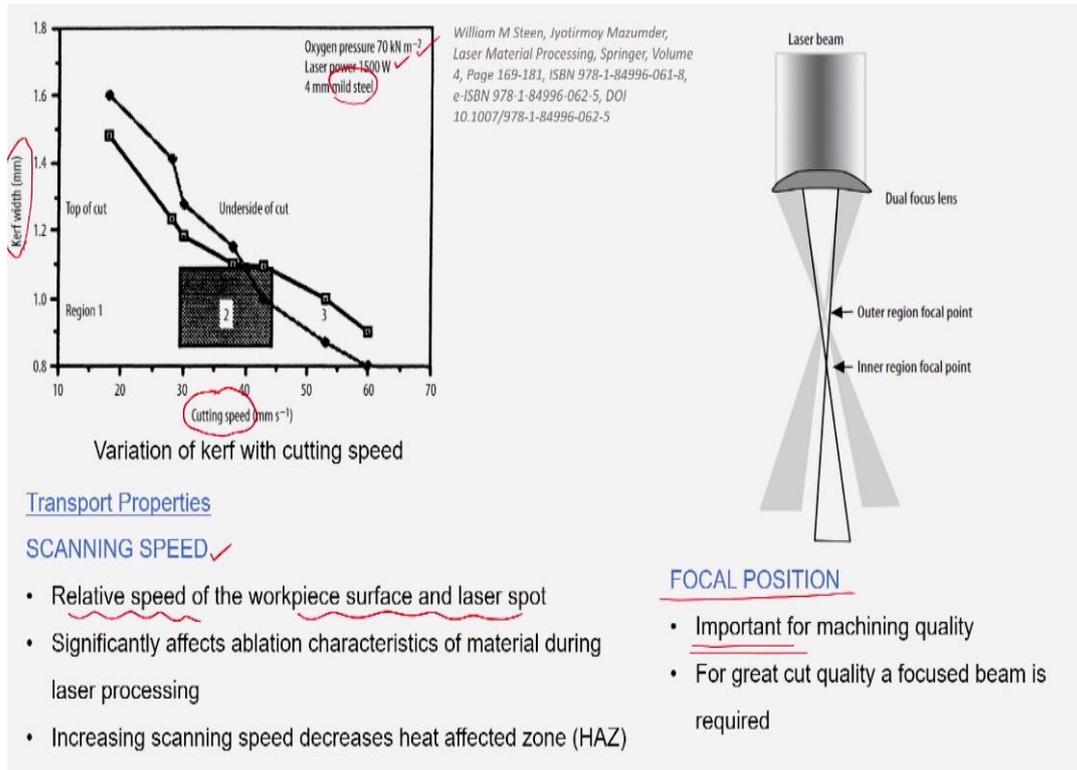
- Shorter the wavelength, higher is absorptivity, and finer focus. This leads to better cut ✓

Fine. let us summarize the effect of various process parameters. We have seen that power. By increasing laser power naturally the cutting depth and the width is getting increased, the kerfs are getting increased. If you want to remove the material at a very rapid pace then naturally we have to apply more power, but it is leading to metallurgical defects, it is leading high heat affected zone and that high heat affected zone is leading to the defects and micro cracks. When we are choosing the power there has to be some trade-off between the defects or the side effects of this application of higher power with respect to the material removal.

Spot size: it is most important as far as the quality of the product is concerned. The spot size is less the density of the laser beam would be very high. We can get accurate machining or precise machining for the lower spot size, but again it is under the control of the CNC based laser machine that you do have or the instrumentation or the optical instrumentation of the machine tool the laser based machine tool that you have.

Wavelength we know that when we are using shorter wavelength then there is a higher absorptivity. Lower the wavelength high absorptivity would be there and we can have a very good quality of cutting during laser based application.

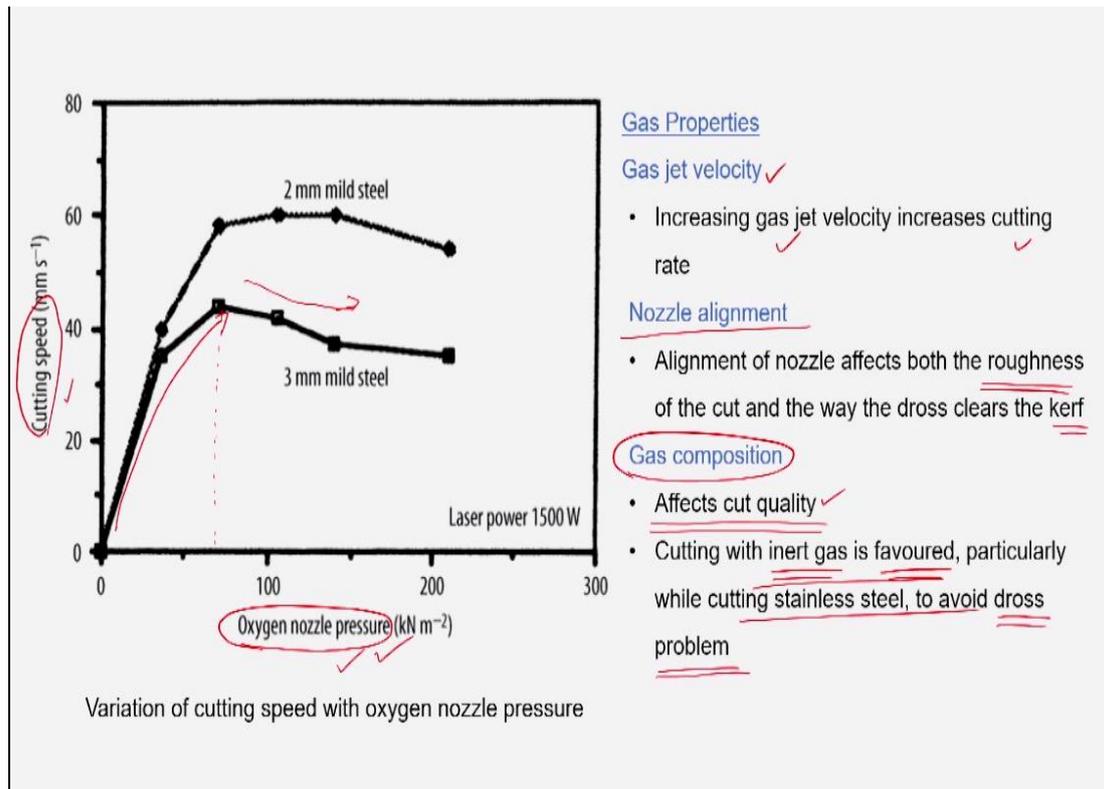
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Now, we are having one more case here that is for effect of cutting speed. Let us consider what is the effect of cutting speed for a constant laser power of about 1,500 watt and the oxygen pressure is also there. This is the metal cutting operation and it is working on a 4 mm of the mild steel. When we increase the cutting speed we are getting reduction in the kerf width. When we increase the cutting speed the interaction time is getting reduced. There is lesser heat conduction and we are getting the kerf width low when we increase the cutting speed by reducing the interaction time. The scanning speed is defined here as the relative speed of the work piece with the laser spot and it is an important parameter, influencing parameter as far as laser based material processing.

Focal position again an important parameter which we have already seen and it is also affecting the quality of the laser beam. There has to be a proper focusing of the laser on the surface. Nowadays the CNC machine tools they are having the integrated or automatic focal position setting based upon the reflection of the laser beam from the surface.

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Now there is another case that we do have. Here we are using the nozzle pressure and oxygen pressure and if we increase the oxygen pressure: what is the effect on the cutting speed or you can say the production rate of the machine tool? If you increase the nozzle pressure or the oxygen pressure here you can see that the cutting speed is getting increased, it will achieve its peak and then it will get reduced. There is a non-linear behaviour of the nozzle pressure with respect to cutting speed. Here you can consider that there is a peak and after that peak there is reduction in the cutting speed that is material removal rate. It is due to the pressure which we are applying by the oxygen it is interfering the laser material interaction and it is not helping for the efficient material interaction. It is disturbing the material interaction. We are using oxygen for extra input, but the pressure that we are applying of the oxygen is not helping to get the required cutting done. The jet velocity has to be carefully chosen if we increase the jet velocity the cutting rate is getting increased

As far as the nozzle alignment is also concerned. Nozzle has to be properly aligned with the laser beam and which is affecting on the roughness of the work part and the kerf width as well.

Gas composition: we have seen that the gas composition either we are using inert gas or the oxygen gas which is affecting the cut quality. If the oxygen is used then there may be oxidation, there may be problem and that will affect the surface quality during laser based machining. In general the inert gases are favored during laser based operations when we cut the stainless steel or steel based products and this inert gas is also helping to reduce the dross related problems, the deposition of dross or dross adherence on the surface.

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Material Properties

Material cut quality is dependent on

- Optical properties
 - ✓ Absorptivity ✓
 - ✓ Reflectivity ✓
 - ✓ Transmissivity ✓
- Material surface properties
 - ✓ Presence of oxide films, plasmas
- Brittleness ✓ →
- Thermal conductivity ✓
- Melting point ✓

In addition to these parameters, the material properties or the optical properties of the material such as absorptivity, reflectivity and transmissivity are also affecting the workpart which we have already seen that the absorptivity has to be more to get the efficient laser based processing.

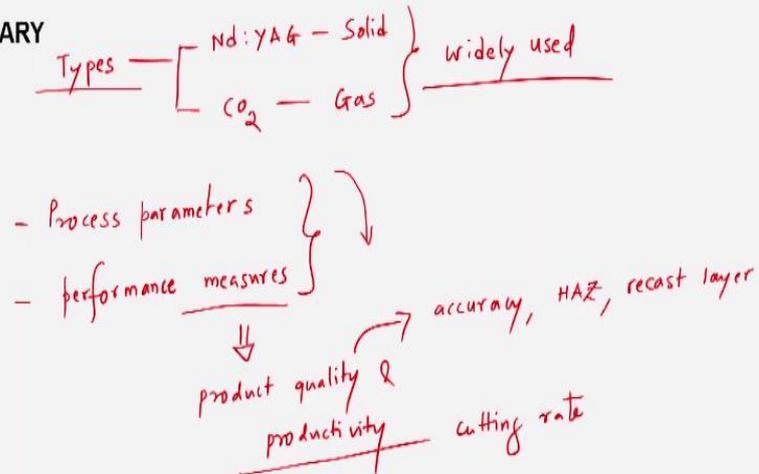
Moreover, the presence of oxide films, plasmas or any dirt on the material surface that also affect the process performance there maybe burning of these oxide fields at the laser material interaction.

Brittleness of the material: if the material is too brittle then there is a chance of having the crack based damage during the laser operations because when we apply the laser beam energy it will convert it into thermal energy and there maybe expansion, but the material is brittle then it may lead to some sort of cracks during its expansion.

Conductivity has to be low as low as possible to have maximum temperature generation, local temperature generation to get efficient metal cutting. The melting point is another factor which is affecting the process performance of laser based processing.

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SUMMARY



Let us summarize today's class. In today's class we have seen various types of prominent lasers and prominently we are using Nd:YAG and CO₂. Nd:YAG is solid laser and CO₂ is the gas laser. These are widely used in the industries. We have seen their construction and working. Then we have seen various process parameters and their effects. Process parameters, performance measures which are used to define the product quality and the productivity. Product quality can be sensed or measured by using geometrical accuracy, heat affected zone, recast layer and the productivity is the cutting rate. We have seen the effect of some of the process parameters, important parameters on this performance measures.

With this I would like to stop for today's class that is the Class 2 of Week 2. I thank you all for your listening and watching this video lecture. See you, bye.