CHARACTERISTICS OF LASER BEAM USED IN MATERIALS PROCESSING

Drd. ing. Ramona LASLAU
„Politehnica“ University – Timișoara
Graduate specialization equipment Textile Technology, Faculty of Mechanical Engineering, Polytechnic University of Timisoara, promotion in 2002. Currently PhD student at the Department of Mechanical Technology.

Prof. dr. ing. Richard HERMAN
„Politehnica“ University – Timișoara

Drd. Remus BOBOESCU
„Politehnica“ University – Timișoara
Graduate specialization Mathematics-Physics, Faculty of Mathematics, West University, Timisoara, 1997. Currently PhD student at the Department of Mechanical Technology

ABSTRACT. Industrial lasers Nd:YAG and CO₂ are used in material processing. Laser beam qualities determine its use as a heat source. It presents the main properties of the laser beam. Aare presented sizes characterizing the laser beam focus and condition for achieving it. It discusses the effect of laser beam characteristics relative to the processes of materials processing.

Keywords: laser beam, focusing, beam shape.

1. INTRODUCTION

The first functional laser with ruby laser was developed by Maiman in 1960. The device used for oscillator excitation was a lamp with neon which emission discontinuous (flash lamp) and deliver the pulse. Ali Javan made in December 1960 first He-Ne laser. This laser radiating in a continuous regime CW and used electrical discharge excitation in a gaseous environment. It soon became the first commercial laser with a power of 1 mW. CO₂ laser was developed by Kumar Patel in 1964 at Bell Laboratories. The assembly that „slow axial flow” and have a power of 1 mW. CO₂ lasers power increased rapidly. This increase was achieved by increasing the length of the tube.

After 1970 the CO₂ lasers were improved in principle by introducing transverse flow and transverse excitation methods and volume of gas constructions. Based on these principles have developed a CO₂ laser with power up to 100 kW. They mainly took place in laser materials processing.

In the 1980s were made in the solid laser field the lasers with Nd: YAG under pulse regime. They came to power up to 1 kW in 1988. Compared with CO₂ lasers
they have a more flexible optical part which allows to use optical fibers instead of mirrors but a lower beam quality. Efficiency in energy transformation for lasers with Nd: YAG is less than 5%. In 1997, Trumpf and Lumonics have developed a laser Nd: YAG of 4 kW with continuous wave emission. By the late 90 was available as a laser power of 10 kW in continuous wave. Lasers with Nd: YAG have started to replace CO₂ laser as a main sources in materials processing. After 2000 was using laser diodes to achieve excitation instead optical lamps [6].

In the present study were presented a selection of factors characterizing the laser beam and make it a heat source that can be used in processing materials. The laser beam properties, monochromaticity, coherence, and directionality and brightness were presented. The conditions of propagation and focusing of laser beams were analyzed.

2. CHARACTERISTICS OF LASER BEAM

Laser realize stimulated emission of electromagnetic radiation. A solid state medium laser have a optical cavity with solid medium in which the electromagnetic radiation emission and amplification take place, a pumping system (usually using pulsed emission lamps), and a cooling system.

Optical pumping and population inversion are achieved in solid, the radiation emitted in the moment system relaxation is amplified in the optical cavity. By one of which is semi-transparent mirror laser beam is obtained. In the following we address the physical quality of radiation emitted by the lasers.

**Monochromaticity** The frequency emitted by the laser is given by the difference in energy between the energy levels for which there is radiation emission. It is given by Planck’s relationship:

\[ \nu = \frac{E_2 - E_1}{h} \]  

where: \( h \) is the Planck’s constant; \( E_2 \) – upper level energy; \( E_1 \) – lower level energy.

The two energy levels between which is laser radiation emission occurs are stable. Thus a single frequency is emitted and amplified in the optical cavity. This means that laser radiation has a single wavelength. This means that the radiation emitted by the laser is monochromatic. Laser with Nd: YAG emits radiation with wavelength of 1.06 µm.

**Coherence.** Coherence of electromagnetic radiation means maintaining a constant phase difference between two points of wave front the wave. Coherence is of two types: spatial and temporal. Spatial coherence is limited to a given area and the temporal coherence is limited to a certain time. Laser radiation have high spatial and temporal coherence compared with conventional light sources.

**Divergence and directionality.** The propagation and directionality of radiation is described by diffraction theory. Maximum intensity of radiation is limited by the angle of divergence.

In the laser medium will be amplified only radiation propagated on direction of optical cavity axis. Construction of optical cavity leading to a low beam divergence which means a high directionality. For perfectly coherent radiation of aperture D space there will be a given divergence angle from diffraction theory. Angle of divergence is given by:

\[ \theta_d = B \cdot \frac{\lambda}{D} \]  

\( B = 1.1 \) is a factor of proportionality

While radiation is partially coherent angle of divergence is greater, aperture diameter being replaced by square root of the area of coherence

\[ \theta_d = B \cdot \frac{\lambda}{\sqrt{Sc}} \]  

**Brightness** The brightness of a light source is defined as the power emitted per unit area and unit solid angle.

\[ B = \frac{4P}{(\pi D\theta)^2} \]  

Maximum brightness is obtained if the radiation emitted is spatially coherent.

\[ B = \frac{4P}{(\pi \lambda \beta)^2} \]  

Electromagnetic modes are standing waves that were formed in the optical cavity. The laser cavity stimulated radiation propagates between the mirrors. Waves for which the propagation distance (twice the cavity length) are whole numbers of wavelengths are standing wave in the cavity. These are call longitudinal electromagnetic modes. Their number is relatively low (below 10) between them is a difference in frequency. Importance in practice is a laser intensity distribution in laser beam section.

This means electromagnetic transverse modes TEM\( p q l q \). Indices have the following meaning: \( p \) – radial
number of fields; \( l \) – the number of angular fields; \( q \) – the number of longitudinal modes. Index \( q \) is excluded, it is considered a single longitudinal mode, so the discussion comes down to the first two indices.

Electromagnetic mode \( \text{TEM}_{00} \) is named fundamental mode. It has the most concentrated intensity and provides the best focusing properties.

He is also called the Gaussian beam because intensity distribution follows Gauss curve, a great maximum followed by a stronger than exponential decrease of intensity. He also is known as single mode beam.

Spatial distribution of that single mode multimode laser beam intensity is given in Figure 2. Laser beam quality parameter is given by BBP (beam propriety product). It is the product of size \( w \) (waist) of unfocus beam and divergence angle \( \theta \) \[2\]

\[
BPP = w \cdot \theta
\]

\( M^2 \) factor is defined as the ratio of the beam parameter given BBP and BBP for Gaussian beam which has the smallest divergence. Laser beam produced by solid medium lasers is multimode type. \( M^2 \) factor values reaching up to 50. Radius or diameter of laser beam is then defined size which means a circular area in which is concentrated most of laser beam intensity. For the Gaussian beam is considered the area where the laser beam intensity decreased \( 1/e^2 \) times.

3. THE FOCUS OF LASER BEAM

Laser beam is focused on the workpiece surface using a lens with focal length \( f \) (Fig. 1). In the focal spot there is a peak intensity. Maximum intensity can be achieved is important in materials processing.

Focusing and interference of radiation occur simultaneously. Focusing of a Gaussian beam produces a focus maximum intensity that contains 86% of laser intensity. For circular Gaussian beam unfocus a minimum diameter of the focal spot can be obtained is given by:

\[
d_{\text{min}} = 2.44 \frac{\lambda}{D}
\]

For a multimode beam \( \text{TEM}_{pl} \) a minimum diameter of the focal spot is given by:

\[
d_{\text{min}} = 2.44 \frac{\lambda(2p + l + 1)}{D}
\]

Factor 2.44 comes from the formula in Fraunhofer diffraction). It is noted that the scope for focusing the beam multimode are more limited than the single mode.

Besides the minimum diameter at that laser beam can be focused the depth of focusing DOF has importance. This is the depth that minimum focusing diameter remained almost constant. The focusing depth DOF is given by laser beam propagation.

Focus of beam produces a convergent propagation followed by a divergent DOF is defined as the minimum distance that beam diameter will keep up constant (within an increase of 5%). For a Gaussian beam this is given by:

\[
DOF = \left( \frac{8\lambda}{\pi} \right) \left( \frac{f}{D} \right)^2 = 2.44 \left( \frac{f}{D} \right)^2
\]

It is noted that the DOF and \( d_{\text{min}} \) are proportionate. This means focusing on a very small spot automatically lead to decrease the focused depth that it can be maintained. To decrease the focal spot diameter is used expansion of laser beam [4].

Fig. 1. Focusing of the laser beam:
\( a \) – diffraction maximum; \( b \) – beam profile.

Laser beam intensity has a complex distribution in space due electromagnetice tranversale modes and in time due to irradiation regime, pulse (with various forms of pulse) or continuous.

To formulate the thermal effects on materials produced by laser is needed simplified forms beam intensity. These are the spatial variation and the temporal variation of beam intensity. By this separation, the two are considered independent also will limit the discussion to multimode laser beam.

Multimode laser beam (Fig. 2) is presented as a more concentrated maximum and minimum strengthen an area considered circular radius \( r_c \). This area is considered to be characterized by average intensity.
Mathematically this is the distribution as a step function:

\[
i(r) = \begin{cases} 
  i_0 & \text{for } r \leq r_s \\
  0 & \text{for } r > r_s 
\end{cases} \quad \text{[W/m}^2\text{]} (10)
\]

Laser pulses can have multiple variation forms with times (triangular, rectangular, repeated maximum). Average intensity can be described as a step function. This type of variation may be considered for continuous regime the system by considering the time infinite and associated with interaction time.

\[
I^*(t) = \begin{cases} 
  0 & \text{for } t < 0 \\
  I & \text{for } 0 \leq t \leq t_p \\
  0 & \text{for } t > t_p
\end{cases} \quad \text{[W/m}^2\text{]} (11)
\]

where \( t_p \) is the laser pulse duration.

By considering the two variations of type step is considered the laser intensity \( I \) actually constant over time and the laser beam spot.

This was presented characteristics of laser radiation that make possible to use it as a heat source in the materials processing. It is linked to high levels of laser radiation properties monochromaticity, coherency, divergence and directionality, brightness. Transverse electromagnetic modes will give the beam shape.

For single mode beam Gaussian type (seen at CO\(_2\) laser) laser spot radius is the distance at which the intensity decreased \( e^2 \) times the maximum. It is characterized by an exponential decrease within that maximum by the edges, the spot being circular. For multimode beam (seen in laser Nd: YAG) there is a complex form of maximum and minimum.

It has a circular form, with an area larger than Gaussian, circular. It will be considered theoretically having an average intensity all over surface which is approximated by a circular form. This is a „top hat” type shape.

4. DISCUSSION AND CONCLUSIONS

Knowledge of the laser beam is an important aspect for its use in processing materials. Such single-mode beam can be focused to smaller spots. Their effect is stronger in the material at the center and decreases steadily to the extremities.

Multimode beam producing larger spots on the material. Their effect on focal spot is constant. If we want to achieve a surface effect there may be a focus in small spot. If we are to achieve a depth effect, such as laser cutting is recommended a larger spot on the surface that maintains a cylindrical shape of the laser beam in depth material.

The above shown were the main physical properties of laser beams involved in laser use for materials processing. It highlighted the physical properties that make from laser beam a tool for material processing. It highlighted the intensity distribution for single mode and multimode laser beam and conditions of their focus.

REFERENCES