# Some Applications of CO$_2$ Laser in Industrial Engineering

BADEA LEPADATESCU
Department of Manufacturing Engineering,
Transylvania University of Brasov
500036 Bvd. Eroilor nr.29, Brasov,
ROMANIA
lepadatescu@unitbv.ro,


GIRDU CONSTANTIN CRISTINEL
Country School Inspectorate Gorj
Tg-Jiu,
ROMANIA
girdu2003@yahoo.com

*Abstract: -* This paper supports the improvement of research, the theoretical and practical aspects of the CO$_2$ laser. Since the first CO$_2$ laser, various research has been carried out which has improved the technology of ferrous and non – ferrous material processing due to the tunable wavelength of $8,7 - 11,8\mu m$ which allows the use of this cutter in various technological cutting operations, drilling, welding. The CO$_2$ laser lines are very intense in the infrared range, and this is obtained by splitting the levels in the subwoofers due to columbic energy and hyperfine splitting due to vibration and rotation, so that the spectrum of the polyatomic molecule is more complex and complicated, making it successfully used in industrial and naval engineering.

*Key-Words:* CO$_2$ laser, manufacturing operations, parameter modeling.

## 1 Introduction

The CO$_2$ laser has a high efficiency compared to gaseous lasers, because the metastable saturation is higher t = 2.5ms. At first, in the manufacture of the CO$_2$ laser, only pure CO$_2$ with λ = 10.6 μm was used in the infrared spectral range, being the most intense. Subsequently, the development of this type of laser has improved due to research in the field using a mixture of gases composed of CO$_2$, N$_2$ and He, which form the active medium, resulting in a polyatomic gas. The study of this type of laser was done by Patel. The energy state of the CO$_2$ molecule depends on the vibration movements inside the molecules [1], [2].

### 1.1 CO$_2$ Laser – description:

Optical pumping is accomplished with N$_2$ molecules that have a near-CO$_2$ resonance level. By shock there is excitation of the CO$_2$ molecules that transmits through the resonance phenomenon from the N$_2$ molecules occurs. The inversion of populations is achieved by collisions of the CO$_2$ molecule with excited N$_2$ molecules, in a N$_2$ atmosphere discharge. Nitrogen has the role of ensuring a good popular laser top level. Laser transitions take place between energy levels of vibration. The resonance optical cavity consists of two concave mirrors located at the ends of the active medium between which the photons circulate and perform oscillatory movements. In the N$_2$ active medium, the nitrogen excites through a gas discharge. It has the role of increasing laser performance with CO$_2$, concentrating luminescent to the center of the tube together with N$_2$ in the mixture, the diffusion of CO$_2$ molecules being reduced to the walls of the tube. The vibration excitation of N$_2$ and CO$_2$ levels that are close in size, $\Delta E = 1,8 cm^{-1}$, takes place in the case of the molecular resonance between CO$_2$ and N2, [1] and [2].
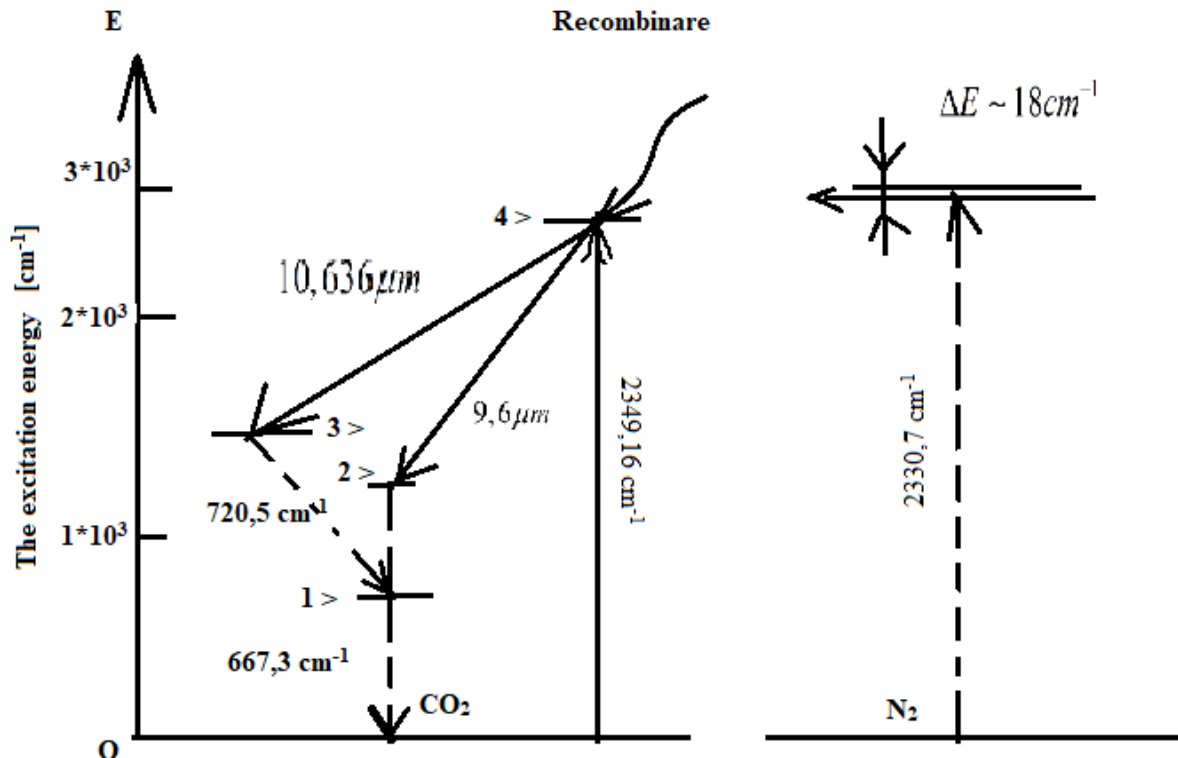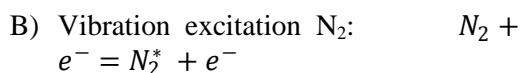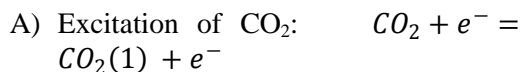
Fig. 1 Schematic energy levels of the $CO_2$ laser.

Optical pumping $0 \rightarrow 4$ is achieved by electronic collisions between nitrogen molecules and the fundamental state of $CO_2$ molecules, excited by$CO_2$ molecules at the level$|4\rangle$, as follows:

A) Excitation of $CO_2$: $\quad CO_2 + e^- = CO_2(1) + e^-$

B) Vibration excitation $N_2$: $\quad N_2 + e^- = N_2^* + e^-$

The energy$CO_2 \cong$ the energy $N_2$, the $CO_2$ molecules take over the $N_2$ energy resulting in population the level$|4\rangle$.

The $CO_2$ laser generates coherent radiation on the vibration-rotation$|4\rangle \rightarrow |3\rangle$ transition which emits a very fine emission line $\lambda = 10.6\mu m$ and between the vibration-rotation $|4\rangle \rightarrow |2\rangle$ transition with wavelength $\lambda = 9.6\mu m$, level$|4\rangle$ being the uppermost metastable level in which population inversion is achieved, being a 4(four)-level laser. Spontaneous transitions occur between lower laser $|3\rangle \rightarrow |1\rangle$ and $|2\rangle \rightarrow |0\rangle$ $CO_2$molecules

respectively [5]. This type of lasers is a gas laser, the radiation emitted takes place in the infrared spectrum (IR), electric excitation, it works in continuous wave, but also in pulses, the energy diagram is that of a four-level laser Fig. 1.

## 1.2 $CO_2$ laser device, experimental description

It consists of a Pirexglass tube Fig. 2, at the ends of the tube there are mirror reflectors (total and semi-transparent in which a hole is emitted by which the laser radiation comes out.) The mirrors are of flat convex or concave shape, being made of Ge and SeZn. The $CO_2$ laser emission power depends on the diameter and length of the tube, and this increases when He is added to the $CO_2 – N_2$ mixture. [2]

Simplified scheme of a $CO_2$ laser: Laser emission– power laser-1, The resonance cavity consists of two concave mirrors, one totally reflecting with the reflection coefficient r = 1, and another partially reflecting with r <1, which allows radiation to exit cavity; Laser tube containing flash, Cooling system is made

withH$_2$O, Gaseous CO$_2$-N$_2$-He fuel feed system; Exhaust gas used for laser operation, Vacuum pump -9, Three phase power supply

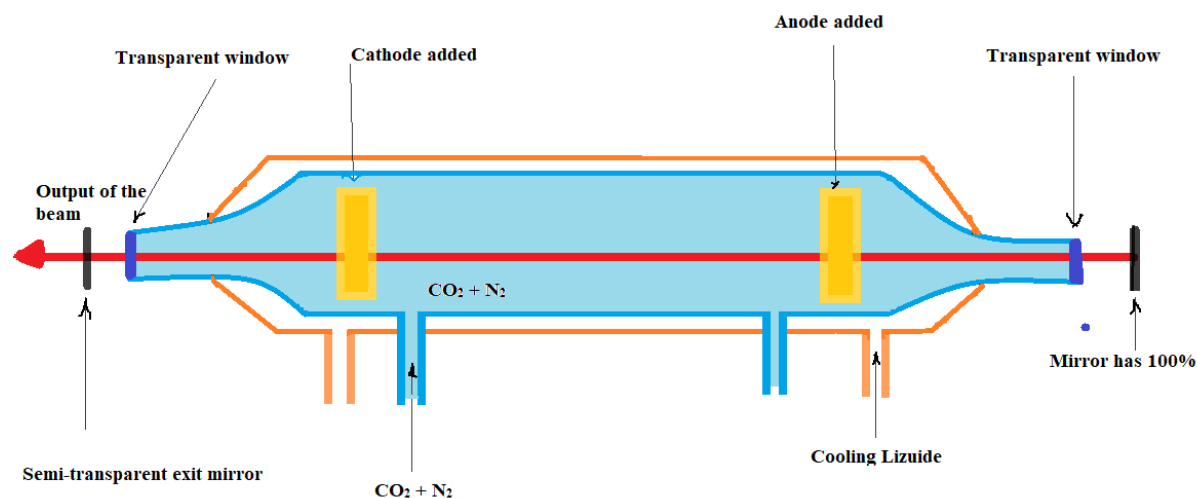[2], Optical quality elements (lenses, mirrors), chrome nozzles, ceramic supports for diures.



Fig.2 Experimental description of CO$_2$ laser.

For the laser with the intensity $I \geq 10^5 \dfrac{W}{m^2}$ it is possible to use successfully the thermal flow. The CO$_2$ laser has Gaussian distribution intensity, λ - the wavelength of the CO$_2$laser is $\cong$ 10.6 μm. The laser source emits radiation that is directed by the mirrors, and finally the laser beam is directed by a convergent lens - *L*. (Glod, 2010). It is important that the laser diode or laser head is in front of the surface of the piece, the laser beam and the CO$_2$ gas are transmitted coaxially to the workpiece [4], [5].

## 2. Operations of technological processing with laser CO$_2$

Cutting is the phenomenon of thermal processing under the influence of laser beam of metallic materials - OL 37 steel sheets, light steel-carbon profiles. Removal of the cut material is done in a liquid state (melted) in which, besides the laser radiation, the reaction between Fe + O > FeO, which is a reaction with heat, exoenergetic, occurs. The cutting process is characterized by the penetration of the material and the appearance of the oxidation reaction. Under laser action these phenomena occur with the melting of the material. By thermal heating, the material is brought to the melting temperature, melted, and the melt overheated. A minimum condition

for the cutting operation is that the material has a latent heat of 2396 J/g. Laser cutting is done by melting the material and removing it under the jet of CO$_2$. The role of oxygen is to remove the molten material, triggering and maintaining the oxidation reaction of *Fe*, but also to protect the convergent lens L. The liquid melt is heated by laminar flow due to the laser source and the asynchronous gas. The surface of the material is made of a melted and resolidified layer due to the cooling of the piece. The exothermic reaction of *Fe* with O$_2$ changes at temperatures between $[1000 - 1400]^o$ C. In the [1200-1900] K range, the oxidation reaction occurs, heating the cutting area. The boiling temperature of the material is 3000K. O$_2$ purity is 99.97%. If oxygen is contaminated with other gases at a concentration of 3%, the cutting speed decreases by 50%, with O$_2$ being important in the cutting area. The CO$_2$ laser heats the metal piece, giving rise to the oxidation process that is maintained by the ash gas, the pure oxygen influencing the chemical reaction. Cutting can be done with the intensity of the laser, having a value between $10^5 – 10^6$ $\dfrac{W}{m^2}$.

The pulse duration of the laser pulse is$10^{-3} – 10^{-2}$s. There is a technical system that measures the cutting width at the top and bottom, the hardness of the OL steel, the roughness of the cut surface at the top and bottom. Theoretical

aspects of research: Interaction of laser radiation with substance, phase transformations of steel under the influence of laser irradiation, energy balance for $CO_2$ laser cutting, determination of parameters according to the width of the cut. Laser irradiation has the effect of producing thermal phenomena in steel. Latent heat is a physical magnitude that characterizes melting, vaporization, melt movement, heating of the material, as well as resolidating it indicating the steel phase transformations. The thermal laser cutting process creates a cutting edge structure characterized by parallel striations. The material is made with a $CO_2$ laser pulse emitting in the infrared range, and interacts for a longer time with the material to melt it. There is a melt that is removed by blowing with a gas jet (oxygen) that is oriented towards the area where it is being processed [4]. Therefore, three thresholds are set: the energy required to obtain the melt, the energy required to achieve the melt movement, the energy required to obtain the displacement. Thus, an incidence of incident laser beam is obtained for the thermal conduction, convection, vaporization phenomena.

## 3. Modeling the parameters with the CO2 laser

In the technological processes of cutting, the melting of the melt is done using a very high power laser and a very short pulse, the removal of the melt is done with the assisted gas jet, with laser absorption we have an increase in the temperature of the T material, and at some point the boiling occurs. Laser Intensity $I$ causes the material to melt and vaporize, laser absorption is influenced by the angle between the laser beam $\theta$ and normal surface (Fig. 3).
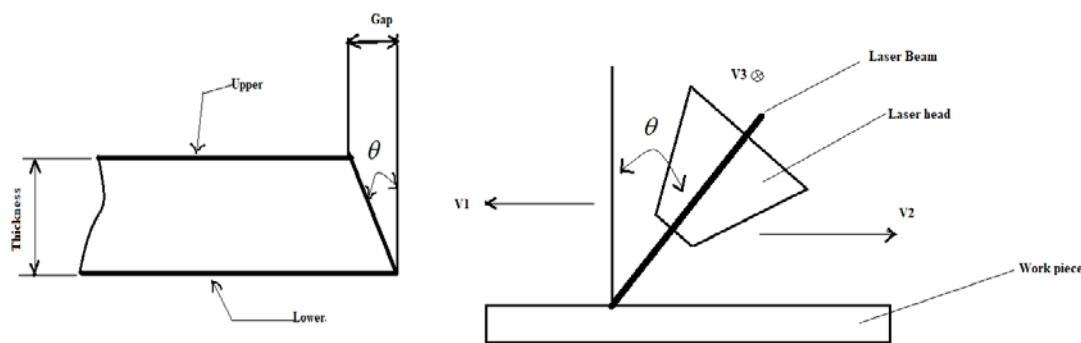


Fig. 3 Parameters to modeling $CO_2$ laser.

Physical quantities used to model the area under laser action [6]:

- $I_{abs}$ the intensity absorbed by laser radiation [3]-relationship (1),

$$I_{abs} = A(\theta)\cos\theta \cdot I_0 \left[\frac{W}{cm^2}\right]$$

- $A(\theta)$ absorbtion coefficient, - $\theta$ angle between normal to surface and laser radiation,

- incidence of the incident beam $I_0 \left(\frac{W}{cm^2}\right)$

$I_{abs} = -k\nabla T + I_v$ Thermal conductivity - $k$, $\nabla T$ - Temperature gradient, $I_v$ - Vaporization / evaporation intensity – relationship (2)

Relationship (3)-Cutting / Drilling Speed [6]:

$$v_T = v_g = k \cdot I_{abs}$$

In the case of laser radiation interactions with the piece, the energy of laser radiation is transformed by the thermal energy due to the phenomenon of absorption and reflection of incident radiation $I_0$ falling on the studied material. By reflection $RI_0$ a part is reflected by the surface of the material, and the other part $(1-R)I_0$ enters the material. The absorption intensity of the radiation that has entered the material is described by an exponential law: $I_{abs} = (1-R)I_0 e^{-At}$, relationship (4), where $R$ is the reflection coefficient and $A$-the absorption coefficient [2].

Table 1.Cuttingspeed at $\theta = 60°$

| Material | Temperature melting°C | Coefficient of absorbtion $A(\theta)$ [%] | Thermal conductivity $k$ $\left[\dfrac{W}{mC}\right]$ | Intensity Incidence $I_0$ $(\dfrac{W}{m^2})$ | Intensity absorbed $I_{abs}$ | Speed cutting $v_T$ $\left[\dfrac{m}{\min}\right]$ |
|---|---|---|---|---|---|---|
| Al | 660 | 0,05 | 237 | $10^6$ | 25 x 10 | 3,61 |
| Cu | 1033 | 0,025 | 399 | $10^6$ | 1,25x10 | 3,04 |
| OT | 3000 | 0,02 | 43 | $10^6$ | $1,0x10^2$ | 0,26 |

Table 2. Cuttingspeed at $\theta = 30°$

| Material | Temperature melting°C | Coefficient of absorbtion $A(\theta)$ [%] | Thermal conductivity $k$ $\left[\dfrac{W}{mC}\right]$ | Intensity Incidence $I_0$ $(\dfrac{W}{m^2})$ | Intensity absorbed $I_{abs}$ | Speed cutting $v_T$ $\left[\dfrac{m}{\min}\right]$ |
|---|---|---|---|---|---|---|
| Al | 660 | 0,05 | 237 | $10^6$ | 43 x 10 | 6,21 |
| Cu | 1033 | 0,025 | 399 | $10^6$ | 21,5x10 | 5,23 |
| OT | 3000 | 0,02 | 43 | $10^6$ | $1,72x10^2$ | 0,45 |

## 4 Conclusions

The industrial laser applications with$CO_2$: $CO_2$ laser MAZAK 500, laser cutting with Trotec Speedy 300, Bystronic laser, TRUMPF brand, NEONA [8],[11],[12], [13] are successfully used for cutting, welding, sealing, drilling, punching, marking, engraving. continuous or pulsed wave. The $CO_2$laser uses average power [4], - 10 W – Low power for superficial engraving and cutting of thin materials, 25-35 W - Medium-low power, for engraving and cutting. 40-60 W - medium power for engraving and cutting of thick materials, 65-80 W – high power, for special operations, 85-120 W – high power, for deep cutting and engraving, over 100kW - power, for special applications with a intensity of the incident

beam $I_0 = 10^{14} \dfrac{W}{cm^2}$ .

Laser cutting of the sheet can be done for sizes of ex. L = 3 x l = 1.5 m and sheet thickness up to: 20 mm for carbon steel, 12 mm for stainless steel, 8 mm for aluminum. Angle $\theta$ - the angle between normal to surface and laser radiation when shrunk will give us a higher cutting speed.The cutting speeds are comparable to the experimental results obtained in the various works, e.g. [9], [10].

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