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STRUCTURED DESCRIPTION FOR OXYGEN ASSISTED LASER CUTTING PROCESS

Mihaela NISTORAN-BOTIŞ*, Remus BOBOESCU,**

Mechanical Faculty, University Politehnica, Timişoara, Romania, ** Engineering, Faculty, University Ioan Slavici, Timişoara, Romania

Abstract: *Oxygen assisted laser cutting is carried out by penetration of the material followed by stabilizing and movement of the cutting front. Pulsed irradiation can be expressed as peak power and ratio spot overlap indepndente sizes.Using a factorial experiment allowed the evaluation of the effects of varied parameters on the cut width. It followed the correlation between varied parameters and physical phenomena for laser cutting.*

Keywords*: laser oxygen cutting, pulse wave regime, spot overlap ratio, cut shape.*

1. INTRODUCTION

The oxygen-assisted laser cutting is a process having a complexity of the physical phenomena that take place.

From the physical point of view the it is noted study of individual physical phenomena such as absorption of laser radiation, material melting, oxidation reaction, heat losses by conduction and gas dynamics to cutting front.

From the technological point of view it is preferred approach as a model of type inputs (influence factors or varied parameters) - output (objective functions sizes directly measured or calculated on the basis of measurements).

There are important differences between the two approaches. Physical exclusive approach leads to detailed consideration of issues ignoring the overall context, and technological approach ignores the basic physical aspects associated with the variation of parameters.

This paper proposes a rapprochement between the two approaches. It will consider a tiered approach to physical phenomena in laser cutting process. This takes into account grouping of physical phenomena for laser cutting in the form of steps and associating variable parameters with sizes that have physical independent effects.

2. LASER CUTTING STAGES

To estimate the effect of influence factors controllable the process of cutting is recommended sequential developmental approach to laser cutting process. The laser cutting process has three important stages:

- material penetration;
- stabilizing cutting front;
- cutting front propagation;

These steps are shown in the figures 1-3.

In the first stage irradiation conditions ensure material melting and its penetration by melting and vaporization. This is expressed by the intensity of the laser beam and laser-material interaction time. In the second stage oxidation reaction and removal of molten material creates an unstable cutting front.

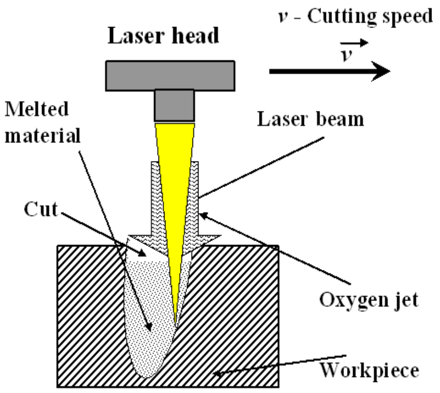

Figure 1 Material penetration

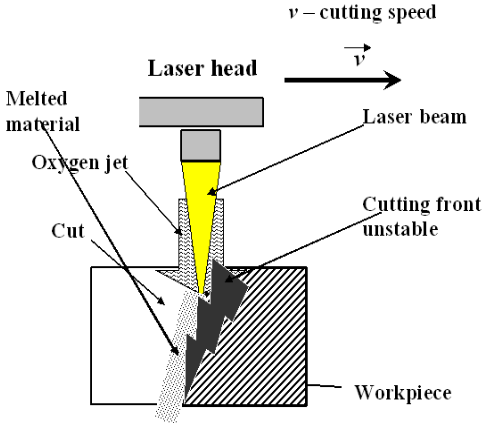

Figure 2 Stabilizing cutting front

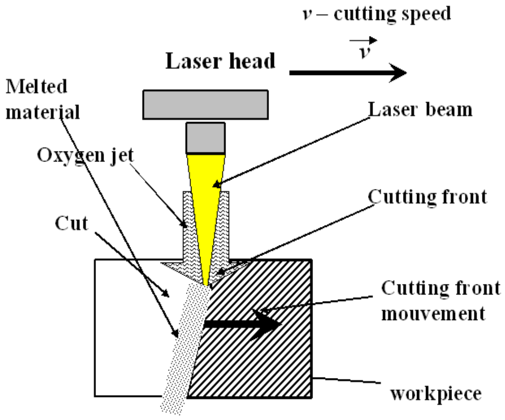

Figure 3 Propagation of cutting front

In the third stage by adjusting the cutting speed ensure the cutting front stabilization, and its movement in the cutting direction.

The advantages of a sequential approach to laser cutting process are that each parameter takes effect only at a certain stage. Action of a parameter is considered in the context of existing action of other parameters. The last stage is the laser cutting process in the development.

3. IRRADIATION CONDITIONS

Pulsed irradiation is specific of many technological laser systems. This is a characteristic design of technological laser systems allow that peak power to be much higher that average power. To laser materials processing submitted advantage stands in the possibility that in relaxation time to dissipate heat into material. Pulsed irradiation increases the number of quantities characterizing the the irradiation.

Thus, it is necessary to understand the relationship between them. A simplified scheme (rectangular pulses) for pulsed irradiation is shown in Figure 4.

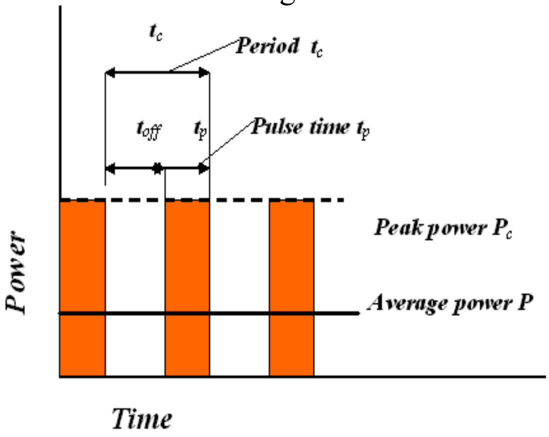

Figure 4 Sizes for pulsed irradiation

Period time t_c[s], represents a full cycle repetition pulses composed by pulse time and pause time between successive pulses. Period is calculated as the inverse of the frequency of pulsation.

$$t_c = \frac{1}{f}\,[\text{s}] \tag{1}$$

The pulse time t_p[s], is the time in which the laser light emission takes place. Depending on the cycle and frequency, the pulse time is given by the following relationship:

$$t_p = \frac{\eta}{f}\,[\text{s}] \tag{2}$$

Length of the interval between pulses t_{off}[s], is that time during laser oscillator does not emit radiation. In relation (2) intervenes coefficien η (cycle or filling ratio for irradiation), which can be calculated from the relationship:

$$\eta = \frac{t_p}{t_p + t_{off}} = t_p\ f\ [\%] \tag{3}$$

where:

$$t_p + t_{off} = \frac{1}{f}\ [\text{s}] \tag{4}$$

For technological equipment used in experiments directly adjusts cycle and frequency, pulse duration is a derived quantity from them. On the other technological systems laser pulse duration is controlled directly. Knowledge of two sizes in relations (2), (3) or (4) defines the pulse irradiation regime used.

The average power P [W] is the power emitted from laser oscillator in a long time and is equivalent to the power emitted continuously.

The peak power Pp[W] represents the maximum laser power. To a rectangular pulse shape peak power is related to the duration of the pulse. The peak power is calculated based on its relationship with average power.

$$P_p = \frac{P}{\eta} \quad [\text{W}] \tag{5}$$

Pulse energy Ep [J] is the energy emitted during the pulse and is calculated as the ratio of average power and frequency.

$$E_p = P_p \cdot t_p = \frac{P}{f}\ [\text{J}] \tag{6}$$

In experiments performed was directly set the average power and frequency of pulsation, pulse energy is determined by them.

Understanding how that can be driven pulse wave irradiation for technological laser system is a first step for ensuring controllability of interaction process laser – substance.

Laser beam intensity I[W/cm^2] is defined as the ratio between the peak power and the laser beam cross-section area.

$$I = \frac{E_p}{t_p \cdot (\pi \frac{D^2}{4})} = \frac{P_p}{\pi \frac{D^2}{4}}\ [\text{W/cm}^2] \tag{7}$$

D - laser beam focal spot diameter

The laser beam intensity present relativity in definition because variation of the time that the peak power is kept constant and the considered surface. To assess the effects of irradiation, laser beam intensity should be defined to define relative to the workpiece surface. It is considered the area of intersection between the laser beam and workpiece.Laser beam intensity is not adjusted directly, but can be evaluated from the experimental conditions. It is important to evaluate the maximum intensity of the laser beam.

Laser beam intensity values will show if that irradiation can cause some physical phenomenon such as melting, vaporization or burning.

Linear energy E$_l$ [J/cm] is the ratio between the average laser power and cutting speed:

$$E_l = \frac{P}{v}\ [\text{J/cm}]$$

(8)

Linear energy is used to describe irradiation both for continuous CW and the pulse regime PW. This size ignores the characteristics of pulsed regime. It will be useful for characterization of physical phenomena that are less sensitive to temporal and spatial differences in irradiation for pulsed regime. It should be material melting and the heat affected area of material.

Irradiation in pulsed regime PW produces spatial differences on the workpiece surface.

Laser spot on the surface of the workpiece is considered to be circular, and is identified for his center point or either through one of its ends.

Regardless of how the laser spot is identified and his dimensions, spot moving over a period is given by:

$$d = v \cdot t_c = \frac{v}{f}\ [\text{mm}] \tag{9}$$

The movement of the laser spot is shown in Figure 5. To characterize the spatial irradiation is introduced as a criterion the way in which the irradiated laser area by one spot covers an area irradiated by the previous spot.

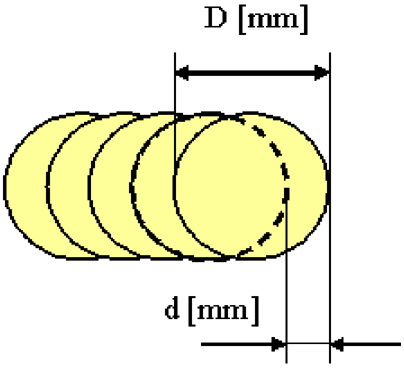

Figure 5 Moving of laser spot. D[mm] - diameter of the spot; d[mm] - moving of spot

Ratio spo (spot overlap) represents the ratio between difference of spot diameter and the distance d traveled during a period and the laser beam diameter.

$$spo = \frac{D-d}{D} \quad [-] \tag{10}$$

Depending on the speed and frequency is obtained the following relation:

$$1 - spo = \frac{v}{D \cdot f} \tag{11}$$

Ratio "spo" has values lower than 1. A value of 1 means there is not displacement. Successive spots are overlap. A value of 0 for ratio "spo" means that successive spots are side by side. Negative values mean that successive spots acting individually and distant each other on the piece surface. The distance between spots is increasing as the ratio spo is smaller, with negative values. Relation (11) plays a role in practical establishment to the cutting speed.

There are cases where when the discussion is confined to positive values of the ratio "spo" it is expressed as a percentage.

Parameters that characterize irradiation plus the laser spot diameter can be grouped so as to use only two independent quantities:

- Peak power (depending on cycle and average power);
- Ratio spo (dependent on speed, frequency and spot diameter).

To express irradiation time differences fpr one point on piece surface is considered continuous irradiation model. Thus, a point on the surface of the material to interact with the laser beam during the interaction time:

$$t_{ic} = \frac{D}{v} [\mathrm{s}] \tag{12}.$$

This is defined as the ratio between the diameter of the laser beam and speed. It represents the maximum duration that a point on the material surface can be irradiated and is independent of pulse time, duty cycle and frequency, quantities characterizing the pulsed regime. During the interaction time several laser pulses can be produced. To establish a link between the characteristics of pulsed regime and interaction time is introduced ratio:

$$r = \frac{t_{ic}}{t_c} [-] \tag{13}$$

The ratio r indicates how many pulsation periods was included in the time during a point on the workpiece.surface was seen in the area of the laser beam. Integer part of the ratio r (exception value 0) indicates the number of consecutive pulses radiating a point on the workpiece surface.

The fractional part of the fraction r indicates that the differences for irradiation times for different points on the workpiece surface are lower than pulse time.

4. EXPERIMENTAL APPLICATION

In the experiments was used a laser with CO_2 with maxim power 2kW of type MAZAK, the operation were in pulsated regime PW. The sheet cold rolled OL 37 3mm thick was used [4] [5]. Cuts were made without completely separated parts named as cut or kerf. For cuts performed have been measured cut width at the top L_s [mm] and at bottom of the workpiece L_i[mm]. Each of these measurements was the average of three different measurements equally spaced along the cut. The cut width L_m[mm] was calculated as the average between the cut width at the workpiece top surface (irradiated by the laser beam) and one at the bottom.

$$L_m = \frac{L_S + L_i}{2} [\mathrm{mm}] \tag{14}$$

To describe the shape of the cut was introduced cut shape ratio given by:

$$R_p = 1 - \frac{L_i}{L_S} [-] \tag{15}$$

Parameter variation was performed according to a factorial full factorial design type 25. Values in central point were: average power P=1150 W, cutting speed v=2150 [mm/min] cycle η=67.5% frequency f= 275Hz, oxygen pressure pO_2 =1.4 bar.

Figure 6 shows the Pareto chart for top cut width.Parameters effects and second order and interactions between them were considered. The most high is the frequency, it is followed by the interaction between power and cycle. Although speed has low effect is noted that the interaction between speed and power has a high effect. Thus, the higher effects are the parameters effects that control the irradiation. Frequency dependence of top cut width shows that the pulse time has a great importance. It is shown that repeated pulses favor evaporation. The qualitative aspect for possibility of material penetration is given to the power. It is noted that there are three interactions of power in the first three effects. It is shown that increase irradiation by increasing power, frequency and cycle has the effect of decreasing the cut width of the at the top piece surface by increasing the vaporization. It is noted that the effect of oxygen pressure is greater than the interactions effects in which it participate. The oxygen pressure has a increasing effect that is less than the parameters effects that control the irradiation.

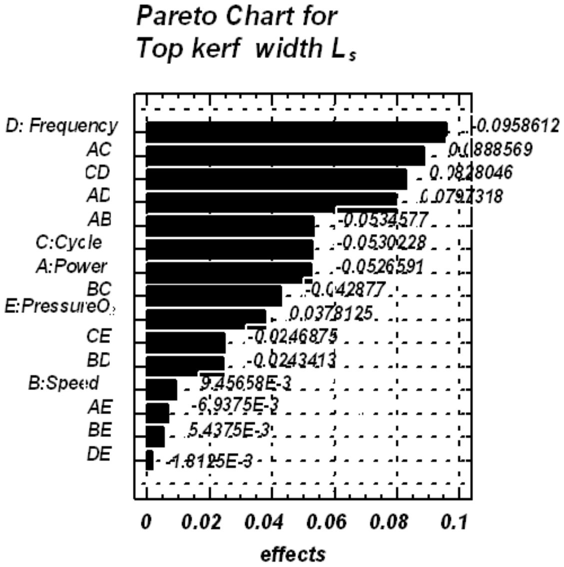

Figure 6 Pareto chart for top cut width

Figure 7 shows the Pareto chart for bottom cut width of the piece. It is noted that the highest effect is the interaction effect between speed and cycle. Power and its interaction with the cycle have the following effects.Effect of oxygen pressure is high by its interaction with frequency. It is shown that the bottom cut width is much more dependent on the speed and oxygen pressure than the top cut width. It is shown that within five effects are found all parameters. Effect of oxygen pressure is low and weaker than the interactions effects in which it participates. It is shown that by increasing the pressure of oxygen favors the the removal of the material in the molten state. This leads to a decrease for contribution of the oxidation reaction and thus decrease the bottom cut width.

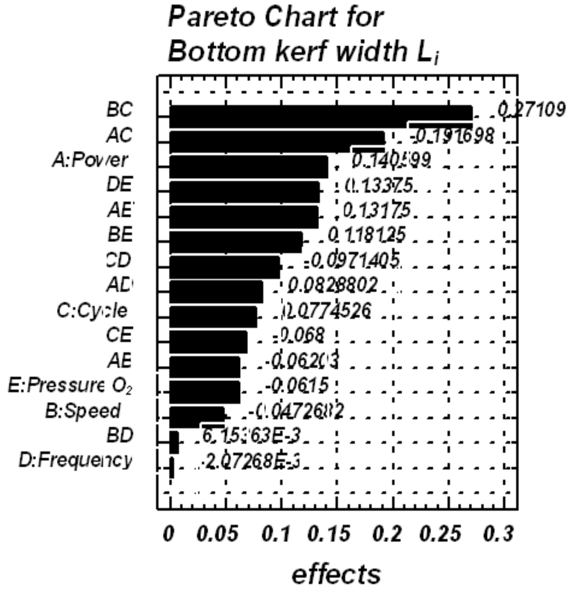

Figure 7Pareto chart for bottom cut width

Figure 8 shows the Pareto chart for the average cut width. It is noted that the highest effect is the interaction between speed and cycle.

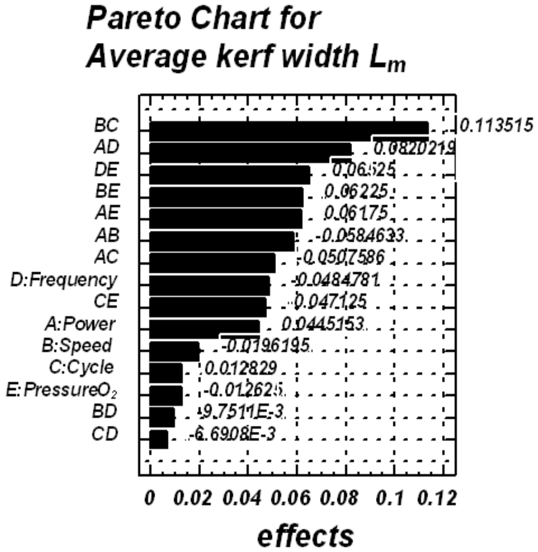

Figure 8 Pareto chart for average cut width

The second and third effect is the frequency interactions with power and oxygen pressure. It is observed so that into the first three effects are included all parameters. It is noted that the effects of interactions between parameters are higher than their parameters effects.It is noted that more interaction of oxygen pressure have high and close together effects.It is shown that pulse time setting by duty cycle and frequency has a significant effect on the average cut width. In determining time interaction time between laser radiation and material also cutting speed contributes. Pareto diagram show that the time interaction between laser radiation and material has the most importance.

Figure 9 shows the Pareto chart for the cut shape ratio.This shows the deformation of the kerf. It is shown that the high effect is the interaction between speed and cycle. It is noted that interactions have higher effects than parameters.

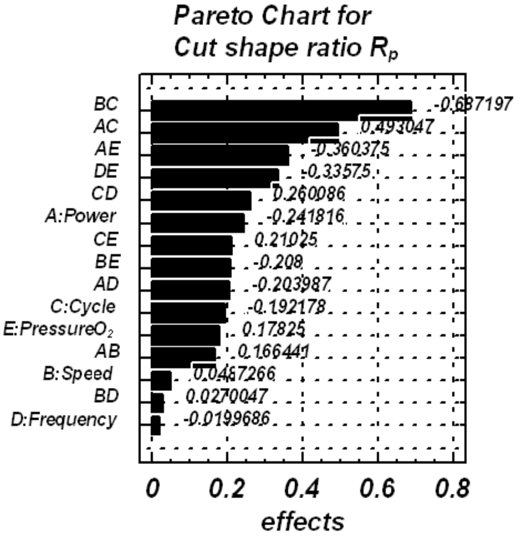

Figure 9 Pareto chart for cut shape ratio

It is noted that the highest effects contain all parameters and decreases frequency role in determining the shape of the cut. For parameters their own effects is observed that the higher effectis the power effect. Power effect of can be directly associated with the penetration of the material. In this case, this effect is related to the deformation of the cut.

3. CONCLUSIONS

The work was carried out a structured description of the steps to achieve oxygen assisted laser cutting. The work was done a time separation of the laser cutting process steps.

For evaporation laser cutting elements physical of cutting front were presented in [1].Here were identified areas of cutting front.

From the physical point of view irradiation is expressed by laser beam intensity and time of interaction between laser radiation and material.

Sizes that characterize irradiation regime for pulse wave PW were presented in [2] and [3]. For pulsed irradiation regime peak power is an expression of the intensity of the laser beam. Interaction time between laser radiation and material has a continuous component and a repetitive component. There are differences between the times of irradiation at different points on the workpiece surface.

For cuts made on steel plate was put in evidence the high effects of frequency for top cut width the piece and the speed for bottom cut width.

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