

# THE INFLUENCE OF CUTTING PARAMETERS ON SURFACE QUALITY AND NITROGEN CONSUMPTION DURING LASER CUTTING

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DOI: 10.17973/MMSJ.2018\_06\_201763

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Unconventional machining methods, or also progressive machining methods, such as laser cutting, waterjet cutting, ultrasound machining, etc. are undergoing a very rapid development. Laser cutting machines often evaluate even 80 parameters in real time. Their advantage is the significantly higher productivity. Many values are defined by the machine manufacturer and can not be changed for a given laser. For custom laser cutting there are 2 essential parameters, adjustable depending on the process gas employed. The aim of this article is to find the setting that will reduce the consumption of process media while maintaining or improving the quality of the machined surface.

## KEYWORDS

laser cutting, consumption of process medium, nozzle diameter, process fluid pressure

## 1 INTRODUCTION

The main observed parameters for CO<sub>2</sub> laser cutting are cutting speed and cutting medium consumption. The cutting speed is to some extent dependent on the performance of the resonator and the overall technical concept of the machine. The consumption of the cutting medium is in particular dependent on the selectable parameters of the machine operator. The fundamental parameters that affect the consumption of cutting medium include nozzle diameter and pressure. The suitable setting of these parameters can be achieved by reducing the consumption of cutting medium while maintaining the same or better quality of the cut. These adjustments result in a shorter financial return and an environmentally friendly operation of the machine. [Eltawahni 2015, Petru 2013, Cep 2016]

## 2 SPECIFICATION OF CONDITIONS OF THE EXPERIMENT

The experiment was conducted in the following conditions and chemical composition is shown in Tab 1.

- Material: AISI 304
- Sample dimensions: 100 x 100 mm, thickness 4 mm
- Machine: Bystronic BTL 3000
- Maximum output: 3 kW
- Wavelength: 10 600 nm
- Kerf: 0.2 – 0.5 mm
- Maximum cutting speed: 169 m·min<sup>-1</sup>

Commercial identification		AISI 304				
Marking according to DIN		1.4301				
Chemical composition		X5CrNi18-10				
C [%]	Cr [%]	Ni [%]	Si [%]	Mn [%]	P [%]	S [%]
max. 0.06	17 - 20	8.5 - 10	1	2	0.045	0.03

Table 1. Chemical composition of the material AISI 304 [13]

### 2.1 Focal level setting

The basic rule is reported in the scientific literature establishes the focal level at the bottom edge at any sheet thickness. It is because of a larger amount of gas allowed to enter the cut, which then better removes melt from the point of cut. Location of the focal point at the lower edge positively affects the verticality of the cut. The second theory considers that the use of inert gas shifts the focal level to 1/3 from the bottom edge of the material, which is because more heat enters the cut than when the focus is at the bottom edge. The third view on the issue assumes (for low material thickness: up to 4 mm) that it is not necessary to remove a large volume of melt, and therefore it is advisable to place the focus higher i.e. on the surface of the sheet. A greater divergence of the beam, and hence also an impaired perpendicularity at small thicknesses is negligible. To confirm or refute the theories described above the focus was gradually placed according to the individual claims. At first the cut was performed according to the recommended machine setting (+ 1.6 mm), then with the focus in 1/3 from the bottom edge (+2.6 mm), subsequently at the bottom edge of the material (+ 4 mm) and on the surface of the material at the level of 0 mm. These three experiments were followed by a fifth experiment, which was intended for ½ of the thickness of the material to be machined. Other cutting parameters remained at the initial value. The following figure (Fig.1) shows the orientation of the positioning of the focus. [Mrna 2015, Petru 2013]

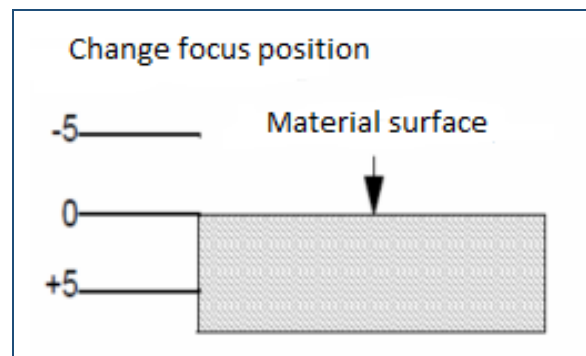


Figure 1. Orientation of the positioning of the focal level relative to the surface of the cut material

### 2.2 Setting of pressure and nozzle diameter

The consumption of the cutting medium depends on the gas pressure and nozzle diameter. These two values affect the formation of burrs and surface roughness. The aim of this experiment is to achieve the desired quality with the use of the lowest possible amount of the cutting gas. According to literature, cutting with nitrogen is carried out usually at a gas pressure of 0,8 - 2 MPa => high pressure cutting. Too high pressure causes burrs at the bottom edge of the cut. A high

pressure improves the quality of the cut and cools the material, but it increases the consumption of the cutting medium. The consumption of the cutting medium can be measured using gas flow measurement, which is part of the machine. This measurement, however, is only indicative and does not have sufficient conclusive value. The consumption for the purpose of the experiment was calculated according to literature. [Bohl 1984, Mrna 2015]

- a) Calculation of the density of nitrogen at cutting medium pressure

$$\varphi_p = \frac{(p_1 + p_2) \cdot M}{R \cdot T} \quad (1)$$

Where  $\varphi_p$  is gas density at cutting medium pressure [ $\text{kg} \cdot \text{m}^{-3}$ ],  $p_1$  is atmospheric pressure (contract value) [Pa],  $p_2$  is cutting medium pressure [Pa],  $M$  is nitrogen molar weight [ $\text{kg} \cdot \text{mol}^{-1}$ ],  $R$  is universal gas constant [ $\text{J} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$ ] and  $T$  is temperature at 20°C [K]. [Bohl 1984]

- b) Calculation of the outflow function

$$\text{Subcritical flow} \quad \frac{p_2}{p_1 + p_2} < 0.528 \quad (2)$$

$$\text{Supercritical flow} \quad \psi = 0.484$$

$$\text{Subcritical flow:} \quad \psi = \sqrt{\frac{\kappa}{\kappa-1} \cdot \left[ \left( \frac{p_2}{p_1} \right)^{\frac{2}{\kappa}} - \left( \frac{p_2}{p_1} \right)^{\frac{1+\kappa}{\kappa}} \right]} \quad (3)$$

Where:  $\psi$  discharge flow function [-] and  $\kappa$  is isentropic exponent of diatomic gases  $\kappa = 1.4$  [-]

- c) Calculation of mass flow rate

$$Q_h = S \cdot \psi \cdot \mu \cdot \sqrt{2 \cdot (p_1 + p_2) \cdot \varphi_p} \quad (4)$$

Where:  $Q_h$  is mass flow rate [ $\text{kg} \cdot \text{s}^{-1}$ ] and  $S$  is nozzle section [ $\text{m}^2$ ] and  $\mu$  is discharge coefficient for conical nozzle  $10^\circ$  [-].

- d) Calculation of volumetric flow rate

$$Q_o = \frac{Q_h \cdot 3600}{p_2} \quad (5)$$

Where  $Q_o$  is volumetric flow rate [ $\text{m}^3 \cdot \text{h}^{-1}$ ] [Bohl, 1984]

The experiment was performed using conical nozzles is labeled HK to increase the kinetic energy of the gas. The focus has been set according to the best result from experiment no. 1 (i.e. at the level of + 2 mm). The width of the kerf at the optimum cutting conditions is in the range of 0.2 to 0.5 mm. In case of using nozzle with a  $\varnothing$  2 mm its size is four times the width with regard to the kerf. It can be assumed that part of the gas that is not efficiently utilized because the removal of the melt from the kerf is provided by only that part of the gas that enters into it. The experiment was then conducted with a chip diameter of 1.75 mm in order to save nitrogen with regard to the original setting, the pressure must not exceed 1,8 MPa. The minimum pressure was determined by previous experiments at the value

of 1,2 MPa for the given material thickness. The subsequently used was the nozzle with a diameter of 1.5 mm. Using a smaller diameter nozzle significantly increases the risk of clogging of the outlet opening with molten metal, it would therefore be appropriate to move the nozzle above the surface away from the material. With a change of another parameter the attempt would lose its comparative value. Another risk consists in the fact that a nozzle with a small opening may be subject to problems with gas convergence, leading to a coarser cut. [Palanker 2013]

### 3 MEASUREMENT RESULTS

#### 3.1 Focal level setting

The experiments show inconsistency with the above theories for adjusting the focal level. The initial focus adjustment at the level of + 1.6 mm results in a quality cut.







Focal point setting				
Cutting speed:		Gas pressure:	Nozzle diameter:	
2.5 m.min <sup>-1</sup>		1,4 MPa	2 mm	
Laser output:		Nozzle standoff:		
100 %		1 mm		
Test No.	Position of focal point [mm]	Visual evaluation	Photography / description	Evaluation
1	0	large burrs on edge		Noncompliant
2	+ 1.6	Quality cut without burrs		Compliant
3	+ 2	quality cut without burrs		Compliant
4	+ 2.6	small burrs in the kerf		Noncompliant
5	+ 4	small burrs in the kerf		Noncompliant

Table 2. Focal point setting parameters

The focus at the level of + 2.6 mm was causing easily removable burrs. The finest cut was made at ½ of the thickness of the material at the level of +2 mm (see in Tab. 2).

### 3.2 Setting the nozzle diameter and pressure

The experiment confirmed the theory, that in cutting with the larger diameter of the nozzle major part of the cutting medium is inefficiently utilized to remove the melt from the kerf. To reduce the consumption of cutting medium and maintain the quality of the cut it is suitable to reduce the diameter of the nozzle and increase pressure. Reducing the hourly consumption of the cutting medium depending on the nozzle diameter and the pressure is shown in Tab. 3.

Setting the nozzle diameter and pressure depending on the consumption of cutting gas						
Cutting speed: 2.5 m · min <sup>-1</sup>			Focal level: 2 mm			
Laser output: 100 %		Nozzle standoff: 1 mm				
Test no.	Nozzle diameter [mm]	Gas pressure [MPa]:	Nitrogen consumption [m <sup>3</sup> · hr <sup>-1</sup> ]	Visual evaluation	Photography	Evaluation
1	2	1,2	27.6	without burrs	-	Compliant
2	1.75	1,2	21.14	without burrs	-	Compliant
3	1.75	1,5	26	without burrs	-	Compliant
4	1.75	1,8	30.87	without burrs	-	Compliant
5	1.5	1,3	16.7	burrs on the lower edge		Noncompliant
6	1.5	15	19.1	burrs on the lower edge	-	Noncompliant



7	1.5	16	20.27	without burrs		Compliant
8	1.5	19	23.9	irregular droplets on the edge		Non-compliant

Table 3. Influence of the nozzle diameter and pressure on the cutting gas consumption

### 4 CONCLUSION

The experiment disproved several long applied theories to determine cutting parameters in the process of laser cutting. In the first phase of the experiment we derived formula for calculating the volumetric flow of gas, where the operator can easily verify consumption of the cutting medium. The main parameters that affect the consumption of cutting medium and the machined surface quality is the position (level) of the laser focal point and dependence of the nozzle diameter and pressure. Fig. 2 shows the graph of the dependence of the nozzle diameter and pressure on the cutting medium consumption. The nozzle that appears as the most versatile for the machined material AISI 304 is the one with a diameter of 1.75, which can be used at a pressure of 1,2 to 1,8 MPa. The lowest consumption of cutting media, however, was achieved by using a nozzle with a diameter of 1.5 mm and a pressure of 1,6 MPa.

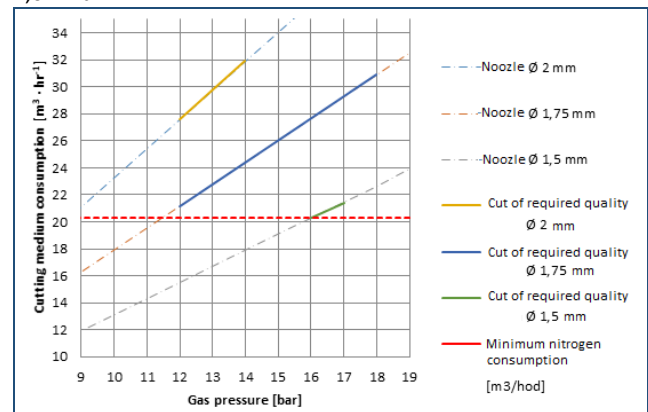


Figure 2. The dependence of the nozzle diameter and pressure on the cutting medium consumption

Producer of machine (Bystronic) has created the graph (see in Fig. 3), which is dependence of diameter of nozzle and gas pressure on consumption of nitrogen. The comparison of our theoretical calculation and values specified by the producer is shown in Fig. 3. Our theoretical calculation of nitrogen consumption has approximately 10 – 12 % higher consumption for individual nozzles tested.

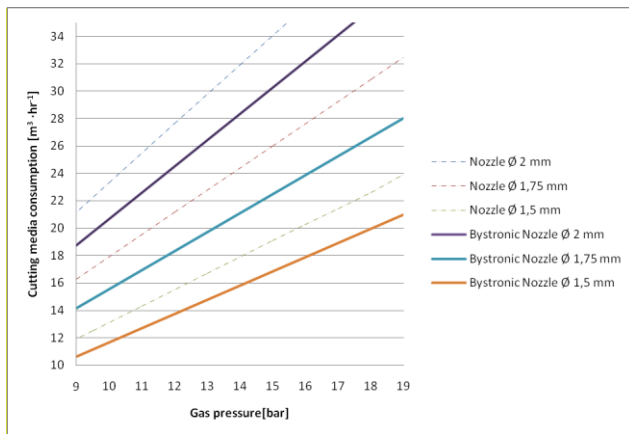


Figure 3. Comparing the calculated consumption with nomogram by company Bystronic.

Company Linde Gas LLC has developed an experimental case study, which focused on right choice of parameters of machine during cutting of stainless steel. These recommended parameters are shown in Table 4. For comparison, the most appropriate parameters were also added to the table, according to our experiment.

	Experiment Linde Gas LLC company	Our recommended parameters
Material	Stainless steel	
Material thickness	4 mm	
Laser power	3 000 W	
Nozzle standoff	0,3-0,8 mm	1 mm
Nozzle diameter	2 - 2,5 mm	1,5 mm
Nitrogen pressure	1,3 MPa	1,6 MPa
Cutting speed	3 m·min <sup>-1</sup>	2,5 m·min <sup>-1</sup>
Gas volume	28 m <sup>3</sup> ·hr <sup>-1</sup>	20,27 m <sup>3</sup> ·hr <sup>-1</sup>
Nitrogen consumption / 1 m of cut	0,155 m <sup>3</sup>	0,135 m <sup>3</sup>

Table 4. Experimentally verified cutting parameters from company Linde Gas LLC [Berkmanns, 2008]

By studying the cutting process in detail, we have managed to reduce the consumption of process media by almost 8 m<sup>3</sup>·hr<sup>-1</sup> (27%). This reduction was mainly achieved by reducing the diameter of the nozzle to 1.5 mm by increasing the pressure to 1.6 MPa and reducing the cutting speed to 2.5 m·min<sup>-1</sup>. For this reason, the cutting speed was reduced in the experiment, the nitrogen consumption in m<sup>3</sup>·hr<sup>-1</sup> is not objective because the cut-off time will be a longer production time. To compare the real reduction in nitrogen consumption, we introduced a new unit that determines the nitrogen consumption per meter. The cutting conditions proposed by us have almost 13% lower nitrogen consumption than those tested experimentally by Linde Gas LLC.

#### ACKNOWLEDGMENTS

Article has been done in connection with projects Education system for personal resource of development and research in field of modern trend of surface engineering - surface integrity, reg. no. CZ.1.07/2.3.00/20.0037 financed by Structural Funds

of Europe Union and from the means of state budget of the Czech Republic and by project Students Grant Competition SP2017/147 and SP2017/149 financed by the Ministry of Education, Youth and Sports and Faculty of Mechanical Engineering VSB-TUO.

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