THE INFLUENCE GAS JET ON THE QUALITY LASER CUTTING METALS

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Abstract

The methods using gas jet in laser cutting are considered. The criteria for the quality laser cutting, such as the absence craters, burrs or ridges on the cutting surface, depend not only on the power the laser radiation, but also on the optimal use the gas jet. An analysis the pressure losses the gas jet in the gap between the nozzle and the metal surface is performed. The passage the gas jet in the cutting zone is significantly affected by the shock wave formed in the gap between the nozzle and the surface the cut metal. Double-jet nozzles provide increased efficiency in removing the liquid phase from the surface the cutting zone.

Keywords: Gas jet, cutting nozzle, dross, shock wave, double-jet nozzle.

I. Introduction

For high-quality laser cutting, a system is required that can control the laser beam and direct it to the processing site with extreme precision. Before starting to cut the contour, the laser beam must first pass through the material at a certain point. The laser cutting process must be accompanied by the supply gas to the cutting zone, which affects the cutting results. The choice gas jet depends on the material being processed and the required quality the workpiece. Oxygen, nitrogen, argon or simply air are used as gas jets for laser cutting.

II. Advantages and Applications Laser Cutting

Compared to other methods separating materials, such as plasma cutting, punching, die cutting or electrical discharge machining, laser cutting has many advantages:

1) Non-contact processing the workpiece is possible.

2) Unlike punching and die cutting, contours almost any shape can be created without a single tool change.

3) Using a laser beam, it is possible to cut both very large contours any shape and small, filigree and complex contours. Geometric contours are processed especially quickly with only a few cuts.

4) The material separation process is carried out with great precision. The width the resulting slot is very small and can be kept almost unchanged. Tolerances up to 0.05 mm can be maintained even in series production.

5) The cutting speed is high. Due to this, it is possible to significantly accelerate the production process, for example, compared to electrical discharge machining.

6) Due to the high energy density, the heat-affected zone can be kept minimal: the depth the hardened layer from 0.1 to 0.2 mm is possible. An oxide layer is formed during oxygen cutting.

7) Slight heating the material minimizes deformation the workpiece.

8) The depth roughness the cutting surfaces is minimal: less than 100 μm. Additional processing the workpiece is not required.

9) Cutting the most frequently used steel grades is performed without the formation burrs, its subsequent removal is not required [1], [2]

III. Methods using gas jet

Today, the laser copes with various cutting tasks and ensures, for example, the formation slots in the thinnest semiconductor chips and high-quality cutting metal up to 30 mm thick. Various cutting methods are used to perform them.

Oxygen cutting: burning cutting. Burning cutting, which uses oxygen (gas purity 99.95, volume percentage 3.5) and creates a pressure maximum 6.0 bar, is used mainly for structural steel. The heated metal reacts with oxygen in the cutting zone, burns and oxidizes. The gas jet blows out the melt formed from the cutting zone together with iron oxides [3].

During the oxidation process, additional energy is generated (exothermic reaction), allowing cutting at a higher speed, as well as processing materials greater thick-ness than is possible when cutting using nitrogen.

The disadvantage this method is the formation an oxide layer on the cutting sur-faces. If the parts are subsequently coated with paint, the oxide layer must first be re-moved. If it protrudes outward, the part becomes unprotected against corrosion [4] [5].

Nitrogen cutting: melt cutting. For melt cutting, nitrogen or argon are used as a gas jet. In this method, the material is also first melted and then blown out the slot using a gas, usually nitrogen. There is no reaction with the molten metal, which allows for oxide-free cutting edges. This cutting method is practiced with a gas pressure 2 to 20 bar (high-pressure cutting) with a nitrogen purity 99.999 and a volume percentage 5.0 (Table 1).

Table 1: *Comparison pressure parameters for burning cutting and high-pressure cutting with nitrogen*

Metal thickness, mm	Oxygen pressure (1.2 mm nozzle), bar	Nitrogen pressure (2.3 mm nozzle), bar
1…3	4.0	20.0
5…30	0.3	20.0

Due to the high gas pressure, almost no burrs are formed on the cutting edges and no slag remains. No additional processing is required.

Cutting with compressed air. Compressed air with a pressure 5-6 bar is used to cut thin sheets metal and blow the melt out the resulting slot. Since air is 80% nitrogen, cutting with compressed air is cutting with melting. The air must be pre-compressed, dried and oil-free. The thickness the sheets being cut depends on the compressed air pressure and the laser power. With a laser power 5 kW and a pressure 6 bar, it is possible to cut a sheet 2 mm thick without burrs. The best results are achieved when cutting aluminum [6] [7].

Laser cutting with plasma support. During laser cutting with plasma support, a plasma cloud is formed in the cut. It consists ionized metal vapors and ionized gas used for cutting. The plasma absorbs part the CO2 laser radiation and transfers additional energy to the cutting zone. As a result, the material melts faster, which helps to increase the cutting speed. The formation a plasma cloud is useful only when cutting thin metal sheets up to 3 mm thick. Thin metal sheets can be cut at a very high speed. With a sheet thickness 1 mm, a speed 40 meters per minute or more is possible. The cutting edge is rougher than with nitrogen cutting with melting. The maximum sheet thickness depends on the laser power. With a power 6 kW, this method can quickly cut aluminum sheets up to 4 mm thick [8] [9].

IV. Statement the research problem

Cutting quality criteria, such as the absence dimples, burrs or ridges on the cutting surface, may depend not only on the laser radiation power, but also on the optimal use the gas jet. The roughness the cut, the squareness, the width the cut, the absence burrs, the cutting speed largely depend on the gas jet control modes (Fig. 1).

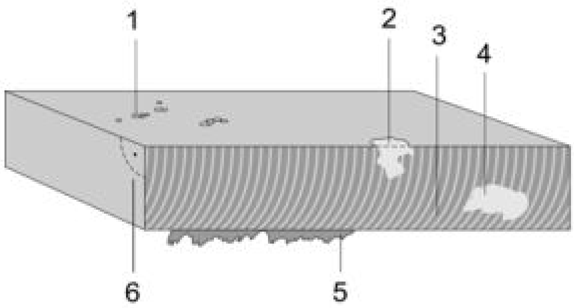


Figure 1: *Criteria for cutting edge quality: 1 – material deposition; 2 – dimple; 3 – ridges on the cutting surface; 4 – washout; 5 – burr; 6 – squareness*

When the laser beam hits the workpiece, the metal heats up to such an extent that it begins to melt or evaporate (Fig. 2).

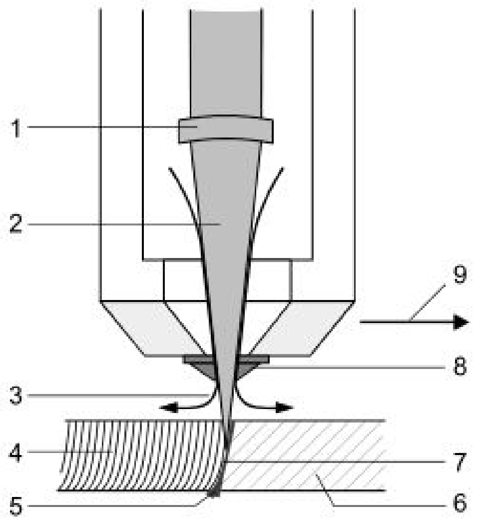


Figure 2: *Laser cutting diagram: 1 – focusing optics; 2 – laser beam; 3 – radial losses gas jet; 4 – cut roughness; 5 – dross; 6 – workpiece; 7 – cutting zone on the workpiece; 8 – nozzle; 9 – cutting direction*

When beam 2 passes completely through workpiece 6, the cutting process begins. Laser beam 2 moves along the contour the part and continuously melts the material. The gas jet comes out nozzle 8 the cutting head together with laser beam 2 and blows out molten metal 5. A narrow cut appears between part 4 and the remainder the workpiece 6 material. In this case, partial pressure losses gas jet 3 occur in the gap between the nozzle and the metal surface. The resulting liquid phase in the laser cutting zone reduces productivity and cutting depth, worsens the quality the side surface the cut and increases the depth the heat-affected zone under it, leading to the formation burrs at its outlet. In this regard, in all laser technological installations, in order to remove the melt from the cutting zone, compressed air under pressure $P_0 = 8 ... 6$ atm, or inert gas with a maximum pressure $P_0 \approx 20 ... 30$ atm is supplied through a special nozzle [10] [11].

The required gas jet pressure for removing the liquid phase from the cutting zone per unit area is determined by the ratio

$$P_f = 0{,}5\left(c_f \rho u^2\right) \tag{1}$$

where c_f is the coefficient characterizing the resistance to the gas flow on the side surfaces the cut, which is a function the Reynolds $R = \rho u b/\mu$;

ρ is the gas density;

u is the gas flow velocity;

b is the size the cutting width,

μ is the gas viscosity [5].

The gas flow velocity is great importance for the effective removal the liquid phase from the cutting zone [12].

The cutting width varies from 0.15 mm (material thickness 1…6 mm) to 0.5 mm (material thickness 20…30 mm). It must remain the same throughout the working area the unit, since otherwise the dimensions and contours the parts will not be observed [13].

Examples studying the control modes and gas jet flow are shown in Fig. 3 and 4 [2]. The consumption gas used for cutting depends on its pressure and the size the nozzle opening. The higher the pressure and the larger the nozzle opening, the higher the gas jet consumption.

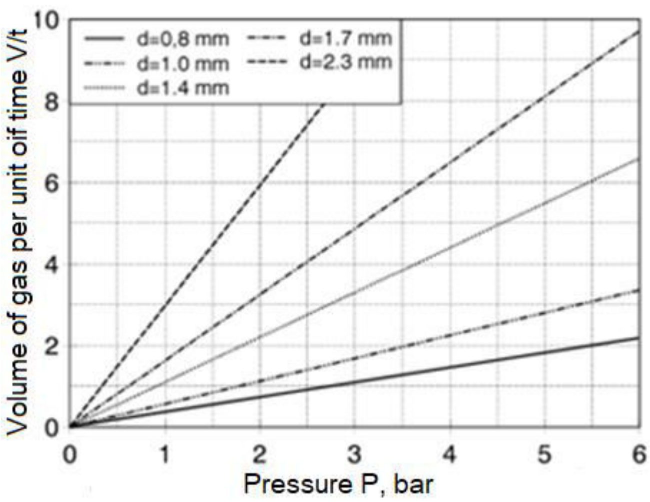


Figure 3: Maximum consumption oxygen used for cutting per hour during continuous cutting [2]

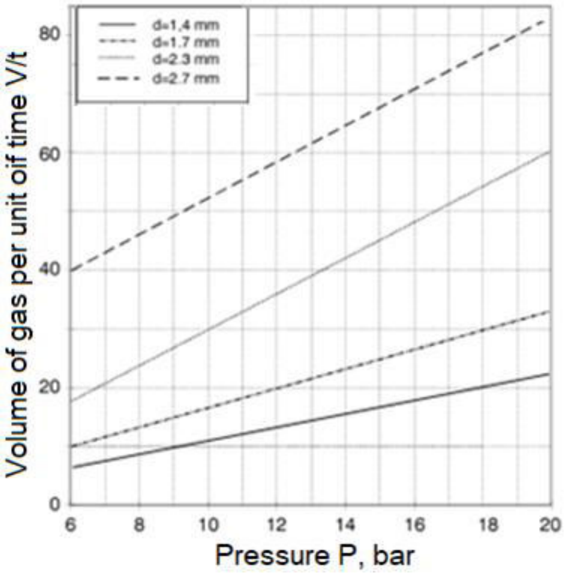


Figure 4: Maximum consumption nitrogen used for cutting per hour during continuous cutting at gas pressure up to 20 bar [2]

During laser cutting, gas jet pressure losses occur, which worsen the laser cutting performance. Therefore, it is necessary to identify the causes and calculate the required gas jet pressure to prevent defects during laser cutting (see Fig. 1). To do this, it is necessary to consider the gas jet flow distribution patterns outside the nozzle.

V. Analysis gas jet pressure losses in the gap between the nozzle and the metal surface

Gas jet pressure losses can reduce the gas jet flow in the laser cutting zone and worsen the quality the cut. Let us consider the gas jet nozzle flow distribution pattern (Fig. 5).

The total pressure the gas flow along the axis its outflow is constant and equal to the sum the static and dynamic components. The shock wave formed in the gap between the nozzle and the surface the cut metal has a significant effect on the passage the gas jet in the cutting zone.

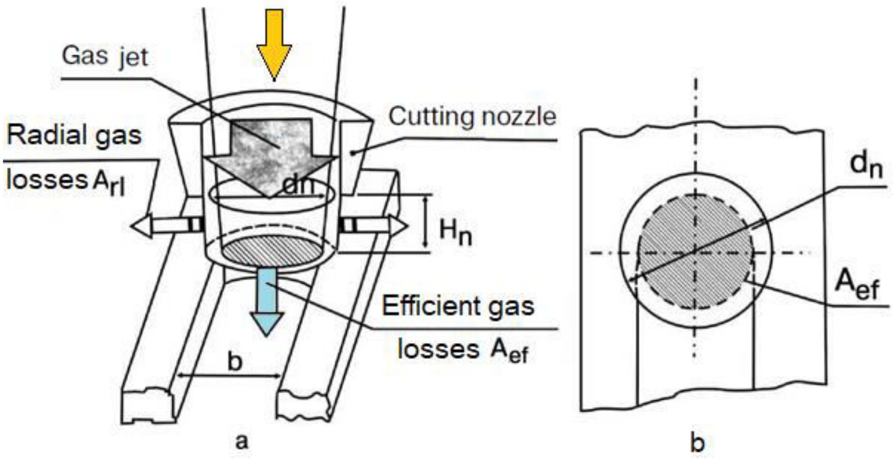


Figure 5: *Nozzle operation diagram [3, 4]*

At the outlet the nozzle with a flow diameter d_n, the gas accelerates to a local supersonic velocity. Behind the nozzle, the gas undergoes adiabatic expansion, the pressure which p_c is determined from the relation

$$p_c = P_0[(2/\gamma_{ad}) + 1]^{\gamma(\gamma+1)} \tag{2}$$

where P_0 is the gas pressure inside the nozzle;

γ_{ad} is the adiabatic index, equal to 1.4 for air.

The pressure loss during gas expansion outside the nozzle is estimated taking into account the area part its flow passing into a cut width b, and the area the other part its flow flowing out in the radial direction, limited by the working distance H_n between the nozzle and the cut [4]. The area the effective part the flow passing into the cut (A_{eff}) is shown in Fig. 4,b by the shaded area. It is limited by the dimensions the cutting zone and the projection the part the circle whose diameter is equal to the outlet diameter the nozzle [14]. The area the cylindrical surface through which the other part the flow flows out in the radial direction is equal to

$$A_{rl} = \pi d_n H_n \tag{3}$$

The value pressure in the effective part the flow, determined from the flow continuity equation, is equal to

$$p_{eff} = p_c A_{eff}/\left(A_{eff} + A_{rl}\right) = f(P_0) \tag{4}$$

Together, relations (2) and (3) show that in order to increase the pressure in the effective part the gas jet flow p_{eff}, it is necessary to reduce the nozzle outlet diameter d_n and its working distance H_n. However, in practice, when $d_n < 1\,mm$ and $H_n < 1\,mm$, the nozzle outlet quickly becomes clogged with products removed from the cutting zone. The rate clogging depends on the cutting depth and the thermophysical properties the material being processed.

It is technically possible to repeatedly increase the pressure P_0 gas jet inside the nozzle and thereby increase the pressure in the effective part the flow p_{eff}. However, here too there is a limitation physical origin. When $P_0 > 0{,}3\,MPa$, the gas flow velocity begins to exceed the speed sound. In this case, a reflected shock wave departs from the surface the material being cut, which limits the gas velocity inside the cut [15]. Therefore, it makes no sense to increase the pressure inside the nozzle more than 0,3 MPa.

A two-jet nozzle, the geometry which is shown in Fig. 6, provides increased efficiency in removing the liquid phase from the surface the cutting zone.

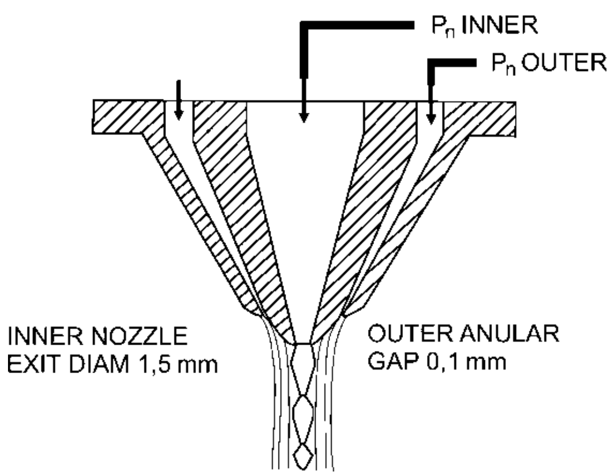


Figure 6: *Geometry a two-jet nozzle [4]*

As can be seen from the examples shown in Fig. 7, the use such a nozzle radically improves the cleanliness the side surface the cut.

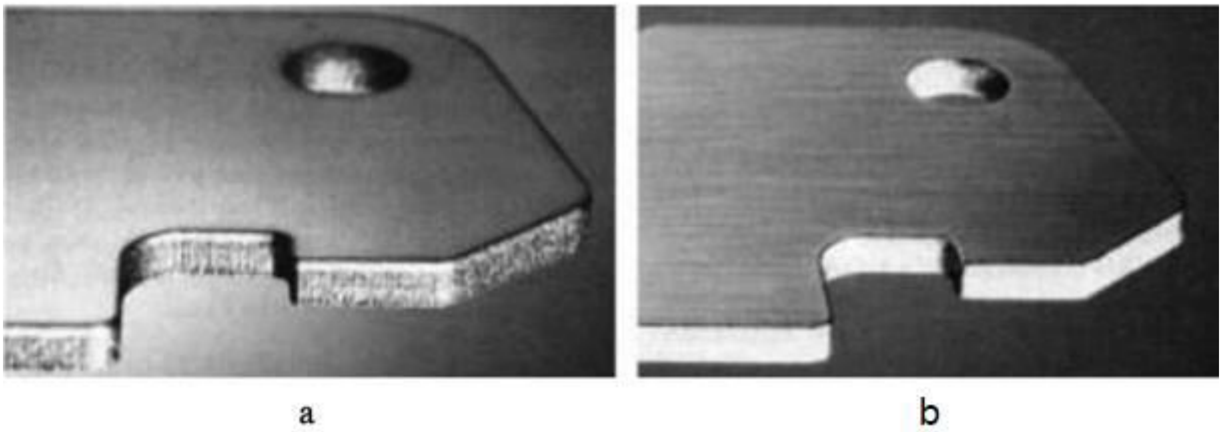


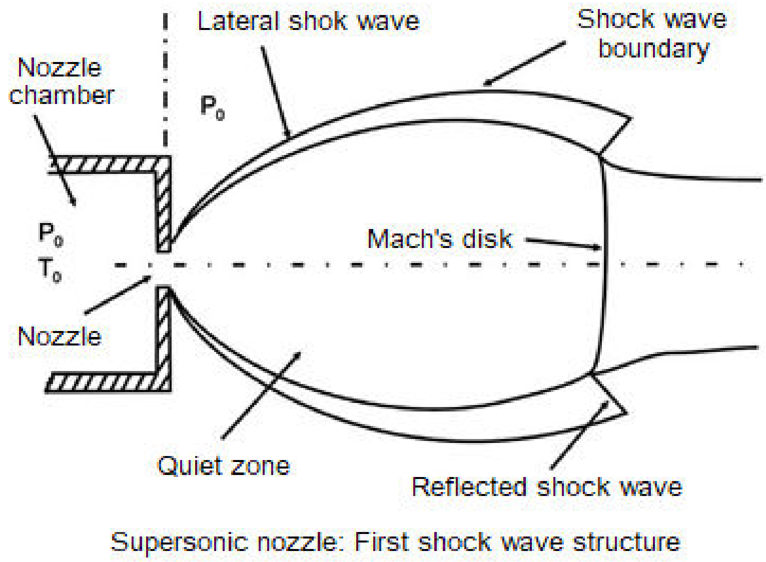
Figure 7: *Quality the side surface the cut in stainless steel 2 mm thick: a – the cut is made using a single-jet nozzle; b – the cut is made using a dual-jet nozzle [4]*

This result is obtained due to the fact that the gas flow exiting the central passage opening with a diameter this nozzle equal to, for example, 1.5 mm (inner nozzle exit diam.), is surrounded by a gas flow flowing out the slotted annular contour (outer anuler gap). Its diameter exceeds the diameter the central flow by several millimeters. The component its expansion velocity is directed radially, including away from the nozzle axis. This limits the pressure losses arising due to the expansion the central flow. Gas is supplied to the inner part the nozzle (inner) under a pressure 0,7 MPa, to the outer part (outer) – under a pressure 0,35 MPa. The nozzle is installed at a distance 4…5 mm above the surface the part [7].

VII. Analysis the dependence the gas jet flow on the shock wave structure

If the ratio the pressure P_0 inside the nozzle to the surrounding atmospheric pressure P_a exceeds $P_0/P_a > 1{,}89$, then the gas jet flow from the nozzle will flow out at a supersonic speed [7]. At a supersonic speed the gas jet, a shock wave is formed as a result its reflections from the atmospheric air. his occurs immediately behind the edge the nozzle, and then the shock wave develops in the form a "barrel", at the end which a gas compaction zone is formed, called the Mach disk (Fig. 8).

Due to the reflections the lateral shock wave from the surrounding air, a second "barrel" is formed behind the first Mach disk, similar in shape to the first, and a second Mach disk. And then a similar structure is repeated several times (Fig. 8). The structure the shock wave changes with a change in the ratio P_0/P_a [7].



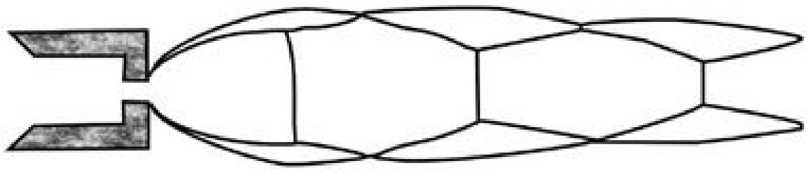


Figure 8: *Formation a shock wave in a supersonic flow*

The effect a shock wave on the pressure value on the surface a part is cyclical and depends on the distance between the part and the nozzle (Fig. 9).

This cyclicity corresponds to the shock wave structure shown in Fig. 8, formed at the specified pressure in the nozzle. When the surface the part is in its calm zone, the pressure on it increases. If it enters the Mach disk zone, the pressure on it decreases sharply, since a smaller amount gas jet passes through the nozzle.

To prevent clogging the liquid phase the molten metal by evaporation products, the nozzle must be placed at a distance 5 mm or 7.5 mm from the surface the part. In this case, the gas jet pressure will decrease by approximately 10% the maximum value, while it is necessary to ensure effective removal the liquid phase from the cutting zone.

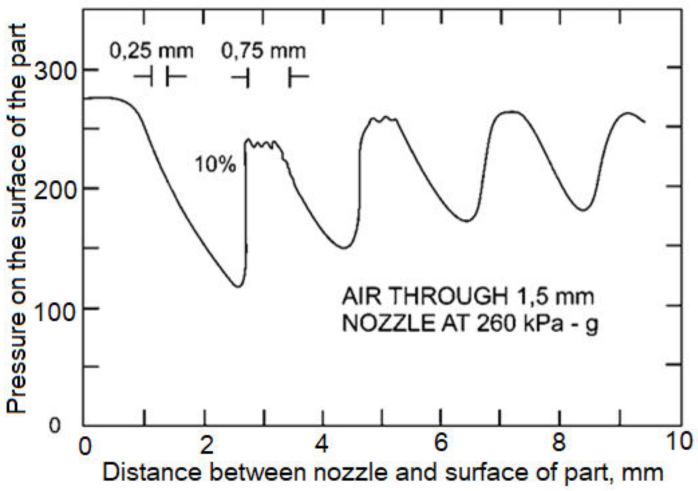


Figure 9: *The pressure on the surface the part depending on the distance between the part and the nozzle*

The best cutting performance to a depth 2 mm in air or inert gas at a pressure no more than 0.5 MPa is achieved by experimentally selecting the distance between the nozzle and the surface the part. When laser cutting to a great depth with a nozzle pressure up to 2...3 MPa, it is necessary to select the optimal values for both the nozzle diameter and its location relative to the surface the part.

VIII. Summary

During gas cutting, when the gas jet is supplied under pressure to a small-diameter nozzle (from 0.7 mm to 1.5 mm), in a narrow gap between the nozzle and the surface the workpiece (up to 2 mm), an interaction the shock wave and its reflection from the metal surface occurs. At supersonic speed the gas jet, as a result its reflection from the atmospheric air, a shock wave is formed. This happens immediately behind the edge the nozzle, and then the shock wave develops in the form a "barrel", at the end which a gas compaction zone is formed, called the Mach disk

The mechanism this process: the gas jet, supplied under pressure up to 2.7 atm, forms a supersonic flow in the nozzle. When exiting the nozzle, this flow collides with the surface the part, forming a shock wave. This wave, in fact, is an abrupt change in the gas parameters, i.e. pressure, temperature and speed. The shock wave, reflecting from the surface the part, interacts with the initial gas flow. This interaction causes additional pressure losses in the gap, which leads to a decrease in the speed the gas flow passing into the hole being processed.

Effect on the cutting process: Pressure losses in the gap can have a significant impact on the efficiency the gas cutting process:

1. Reduced cutting speed: Reducing the gas flow leads to a decrease in the cutting speed, since the pressure required to melt the metal is reduced.
2. Deterioration in cut quality: Insufficient gas pressure can lead to uneven cut edges, burrs and other surface defects.
3. Increased gas consumption: To achieve the required pressure and cutting speed, it may be necessary to increase the gas supply, which leads to increased costs.
4. How to minimize the impact shock waves:

Optimization nozzle geometry: A properly selected nozzle shape, taking into account the gas characteristics and cutting mode, can reduce the intensity shock waves. Use special nozzles: There are nozzles that facilitate a smoother transition the supersonic flow from the nozzle to the gap, which reduces the intensity shock waves.

Use gas mixtures: The use certain gas mixtures can change the characteristics shock waves and reduce their impact on the cutting process. The interaction shock waves with the surface the part affects the efficiency laser cutting, leading to pressure losses, reduced cutting speed and deterioration in cutting quality. To improve the efficiency laser cutting, it is necessary to take this factor into account and apply appropriate measures to minimize the impact shock waves.

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