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THE INFLUENCE PATTERNS OF NOZZLE DESIGN AND TECHNOLOGICAL PARAMETERS OF GAS-ASSISTED LASER CUTTING ON THE STAGNANT PRESSURE OF ASSISTING GAS

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Abstract. The paper proposes and implements a methodology for experimental measuring of the dimensions of the action zone and the amount of pressure, which ensures the removal of the liquid phase during gas laser cutting and is created by the flow of the assist gas on the surface of the part. During the research, based on a serial LTS-PRO-6000-1530-LD machine of Aramis company, serial one-channel and two-channel nozzles of Thermacut company with an outlet diameter of 1.5 mm were installed in the optical head of the machine. In the experiments, air with the gauge pressure at the nozzle inlet of 0.5 MPa and 1 MPa was used as the assist gas. The regularities of the influence of the nozzle design, the gap between the nozzle and the part, and the gauge pressure at the nozzle inlet on changes in the diameter of the supersonic jet of the assist gas and the amount of pressure it creates exerting the surface of the part under technological conditions of gas laser cutting have been established. The obtained array of experimental data has shown that the traditional approach to the use of the existing range of serial nozzles makes it problematic to effectively design gas laser cutting processes with maximum productivity and reproducibility of the cut quality. This is related to complex phenomena in the supersonic jet, which determine the high sensitivity of the pressure value on the part's surface to changes in the nozzle geometry and process technological parameters. As a result, there is no understanding of what kind of pressure is created by the jet of the assist gas in the cutting zone under certain technological parameters of the process. The methodology proposed in this paper makes it relatively easy to create "passports" for the nozzles that each machine is equipped with. Thus, it becomes possible to take into account the real value of the assisting pressure field in the cutting zone when designing a specific technological process. As a result, productive high-quality cutting is more

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reliably ensured on a given technological installation and the level of process reproducibility is improved. Experimental verification has demonstrated a fairly good correlation between the local stagnant pressure of the assist gas jet and the maximum laser cutting speed and the cut quality.

Keywords: gas laser cutting, assist gas, nozzle, supersonic jet, fiber optic laser.

Introduction

In modern technological installations for gas-assisted laser cutting of metals, air of various pressures (0.2-2 MPa) and a wide range of nozzles, both in terms of design and geometric dimensions (Riveiro *et al.*, 2019), are widely used as an assist gas. The assist gas plays an important role in metal laser cutting technologies. In (Olsen, 2006) the maximum possible cutting speed for different workpiece thicknesses is determined as a function of the laser power and the assist gas jet pressure. That is, the pressure of the assist gas jet on the surface of the workpiece has a significant impact on the productivity and quality of the cutting process. This is because this pressure determines the parameters of melt removal from the cutting zone. Obviously, as the laser power increases, the material melting rate cannot exceed the rate of its removal (Halm *et al.*, 2021). Because of this, there are many works devoted to the various roles of the assist gas in gas-assisted laser cutting technologies. Some of them study the aerodynamics of supersonic assist jets (Darwish *et al.*, 2019), others focus on the parameters of jet interaction with the workpiece (Zhang & Gogos, 2004; Chen *et al.*, 2001). T. Qin *et al.* (2022) consider the role of gas jet pressure in laser cutting of carbon fiber reinforced plastics. In (Ullah *et al.*, 2022), during laser cutting of aluminum alloys, the assisting gas pressure is taken as the basic parameter for process optimization along with the radiation power and cutting speed.

Other scientists study the influence of the composition and purity of the gas. In the paper (Zhou *et al.*, 2016), authors study the role of supersonic nozzle in fiber laser cutting of stainless steel using Ar gas as an assist gas. It has been shown that the internal shape of the supersonic nozzle produces a stable jet at the outlet and may be better than a conventional nozzle if we plan to eliminate streaks on the workpiece area during fiber laser cutting. P. Wen *et al*. (2016) propose a method for designing a supersonic nozzle based on a two-dimensional isentropic calculation of the dynamic gas pressure. The use of oxygen as an assist gas should take place at full utilization of the combustion heat from the Fe-O reaction. The dynamic behavior of the oxygen and gas flow, determined by the nozzle structure and cutting parameters, is a key factor affecting productivity and cutting quality.

The role of the nozzle design in shaping the parameters of the assist gas jets is studied in (Fieret *et al*., 1987). However, most researchers note that the potential of modern high-power (2-12 kW) fiber lasers is not always fully utilized due to the inefficient removal of molten material by the assist gas jet (Riveiro *et al*., 2019). Therefore, many researchers conduct numerical experiments to model the process of removing molten material from a laser cut kerf (Yagi *et al*., 2021). The results presented in this paper J. Pocorni *et al.* (2017) suggest that the cut front produced when cutting stainless steel with a fiber laser and a nitrogen assist gas is covered in slow moving humps which themselves are covered by a thin layer of faster moving liquid. M. Borkmann & A. Mahrle, (2021) showed that in cutting metals with solid-state lasers, a characteristic cutting edge structure is generated whose formation mechanisms still elude a consistent explanation. Several studies suggest a major contribution of the pressurized gas flow. Particular emphasis must be devoted to the gas boundary layer and its developing flow characteristics, since they determine the heat and momentum exchange between the cutting gas and the highly heated melt surface and thus the expulsion of the molten material from the kerf.

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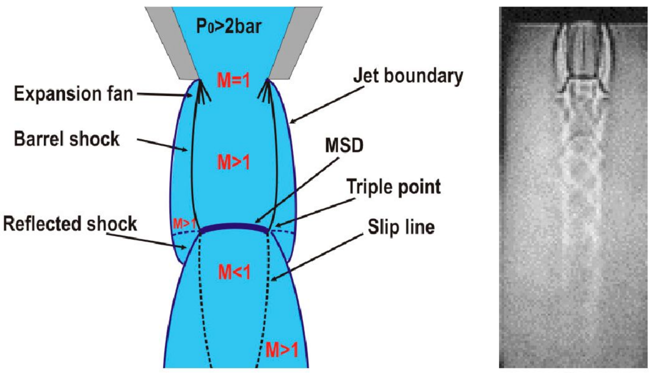
Hence, it is clear how important information about the pressure parameters in the cutting zone is when designing technological processes for a particular technological installation. Based on the above, the authors had a goal to develop a methodology and appropriate equipment and to conduct a set of studies that would allow determining for each nozzle design the change in pressure value under certain technological parameters of gas-assisted laser cutting.

This makes it clear how important information about the pressure parameters in the cutting zone is when designing efficient technological processes. Based on the above, the authors set goal to create a framework for more reliable provision of conditions for productive high-quality gas laser cutting using a specific technological installation and increase the level of process reproducibility. The goal is achieved by developing a methodology, appropriate equipment, and conducting a set of experimental studies to establish numerical regularities of the dynamics of changes in the diameter of the supersonic assisted gas jet and the pressure created by it in the cutting zone, depending on the nozzle design and specific process parameters.

Literature review

It is well known from the theory of gas dynamics that conical nozzles can provide a maximum jet velocity at the nozzle outlet equal to the speed of sound in the surrounding medium (Mach number = 1). For air, the condition for the assisting jet to reach the speed of sound at the nozzle tip is met if the ratio of the pressure inside the nozzle P_0 to the pressure of the surrounding atmospheric air P_a exceeds 1.89 (P_0/P_a >1.89), i.e., in almost all possible cutting regimes. However, since under such conditions the static pressure in the jet always exceeds the atmospheric P_a, an additional expansion of the jet occurs immediately after the nozzle tip and, accordingly, its velocity becomes supersonic (Laval nozzle effect). At supersonic jet velocity, a shock wave is formed as a result of its reflection from the atmospheric air. Subsequently, the shock wave propagates in the form of a "barrel", in the lower part of which a gas compression zone is formed, which is commonly referred to as the Mach disk. Due to the reflection of the lateral shock wave from the surrounding air, a second "barrel" similar in shape to the first is formed behind the first Mach's disk. In a free-flowing jet, this structure can be repeated several times. Immediately after the Mach disk, the flow velocity of the assist gas becomes less than the speed of sound. Thus, the structure of the jet has a complex axisymmetric structure with significant fluctuations in diameter and flow rate (Fig. 1).



a b

Figure 1. Scheme (a) and shadowgraph image (b) of the free jet emerging from a conical nozzle commonly used in laser fusion cutting for an operating parameter range P_0/P_a >1.89 (Riveiro *et al*., 2019)

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The pressure of the assist gas (cutting pressure) on the surface of the workpiece is directly determined by the jet stagnant pressure. Uneven flow velocity and diameter along the length of the jet due to the formation of shock waves leads to fluctuations in the assist pressure on the surface of the workpiece in the cutting zone. This, in turn, affects the rate of molten material removal and, accordingly, the productivity and quality of cutting and definitely impairs the reproducibility of the process.

In the paper (Miller, 1988), the author proposes to determine the distance from the nozzle tip to the first Mach disk using the following empirical equation:

$$\frac{x_{\text{м}}}{d} = 0.67\sqrt{\frac{P_0}{P_a}} \tag{1}$$

where $x_{\text{м}}$ – distance from the nozzle tip to the first Mach disk;

d – outlet diameter of the nozzle;

P_0 – full pressure inside the nozzle;

P_{a} – atmospheric pressure.

The accuracy of this equation raises some doubts because it does not take into account the thermophysical parameters of the gas and the fact that the jet is not free in gas-assisted laser cutting. However, it is clear from the above that changes in the P_0/P_{a} ratio, the design and outlet diameter of the nozzle, and the stand-off between the nozzle and the surface of the workpiece lead to significant changes in the jet structure and, accordingly, uncertainty in the actual value of the cutting pressure of the assist gas. This uncertainty complicates the design of high-performance modes and worsens the level of process reproducibility even with minor changes in these parameters.

Materials and methods

Based on the above, the task was set to create an installation and an appropriate methodology that would allow obtaining sufficiently accurate experimental data on the patterns of change in the jet diameter and the value of the assisting pressure on the surface of the part when using a specific type of nozzle, model of technological installation, and parameters of the gas-assisted laser cutting process.

The general layout and 3D model of the research installation are shown in Fig. 2.

The proposed method of measuring the jet diameter and the pressure of the assist gas on the surface of the part is based on the use of a specially designed installation (Fig. 2, b). The installation is fixed on the working table of the machine (Fig. 2, a). The operator, using a tuning laser and feed drives, sets the nozzle of the optical head 1 so that the central axes of the nozzle and the force transmission cylinder 3 (structurally placed steplessly with respect to the top plate 2) coincide. Then the stand-off tracking unit determines the coordinate of the Z-axis when the nozzle`s end face touches the surface of the cylinder 3, taking it as the zero reference point. A highly sensitive 0.01 mm thick copying film is fixed on the surface of the plate 2 by magnetic posts 5. The gauge pressure is set by the machine's pneumatic system and is additionally controlled by an external manometer. Sensor 7 measures the force from the jet 6 with an error not exceeding ±0.00981 N. The prints from the jet pressure on the copying film were photographed and processed using CAD system. As a result, the error in determining the diameter of the assist gas jet on the surface of the part did not exceed ±0.01 mm. Fig. 3 shows a sample of the results of measuring the jet diameters after one of the experiments. An optical fiber with a diameter of 0.5 mm was used as a reference for determining the spot diameters. The passport deviation of the optical fiber dimensions from the nominal value does not exceed 1 μm. The average stagnant pressure of the assisted jet was calculated by dividing the measured force by the spot area.

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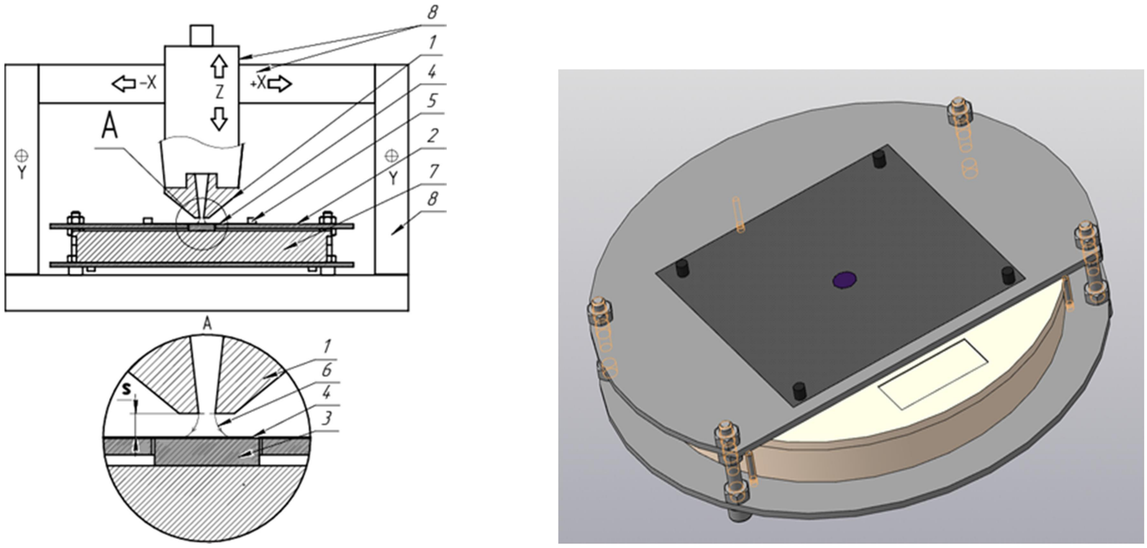

a b

Figure 2. General scheme for measuring the jet diameter and assist gas pressure (a), 3D model of the installation for recording the jet diameter and assist gas pressure (b):
1 – single-channel and two-channel nozzles from Thermacut with an outlet diameter of 1.5 mm;
2 – top plate of the installation for recording the force of the assist gas pressure;
3 – cylinder for transferring the force from the action of the assist gas jet to the meter;
4 – copying film for recording the jet diameter; 5 – magnetic film fixation racks;
6 – a jet of assisting gas; 7 – force sensor;
8 – coordinate motion drives of the serial machine LTS-PRO-6000-1530-LD by LTD Aramis;
s – controlled stand-off between the nozzle and cylinder 3

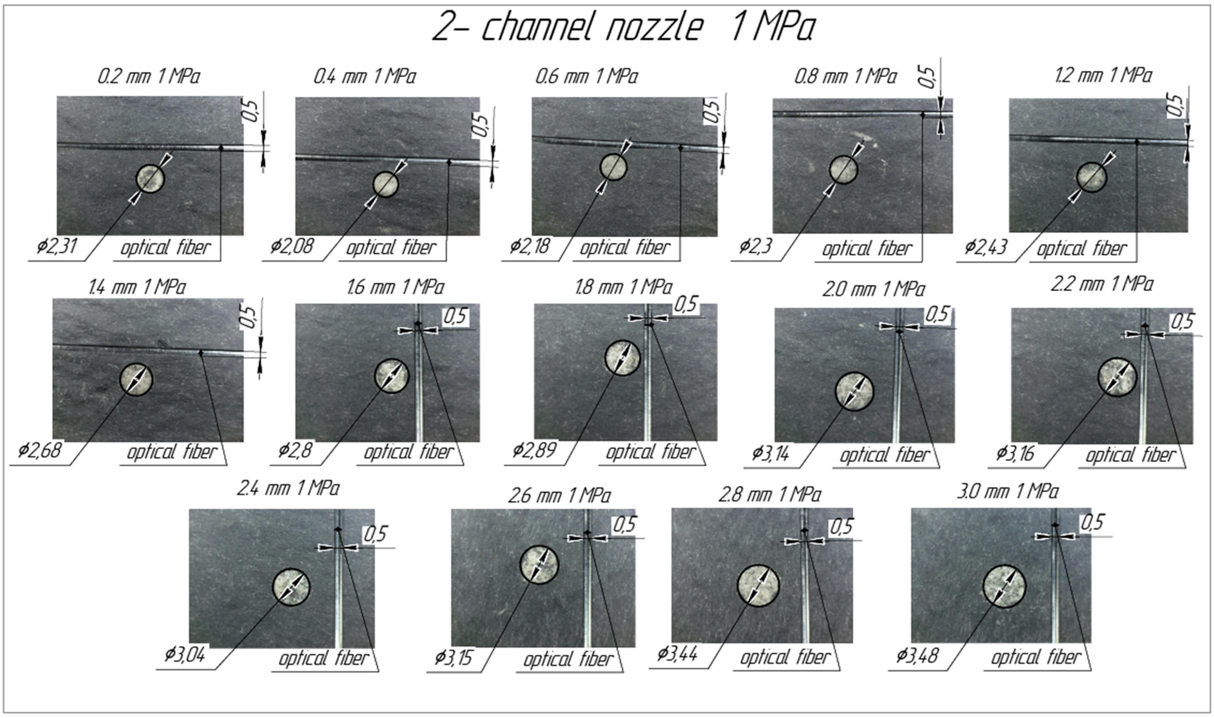

Figure 3. Results of determining the diameter of the assisting gas jet using CAD system

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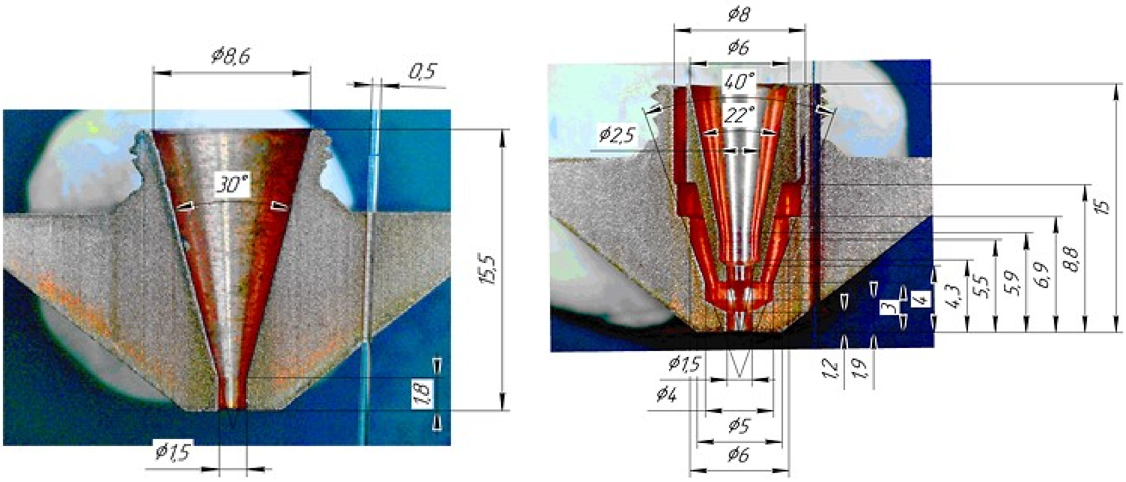
The studies were carried out using the serial machine LTS-PRO-6000-1530-LD from Aramis. The optical head of the machine was equipped with serial single-channel and dual-channel nozzles from Thermacut with an outlet diameter of 1.5 mm (Fig. 4). In the experiments, air with a gauge pressure at the nozzle inlet of 0.5 MPa and 1 MPa was used as an assisting gas.



a b

Figure 4. Configuration and geometric dimensions of Thermacut's standard single-channel (a) and dual-channel (b) nozzles with a center bore diameter of 1.5 mm

The value of the stand-off s between the nozzle section and the force transmission cylinder 4 of the recording system (Fig. 2) was set and controlled by the stand-off tracking system of the LTS-PRO-6000-1530-LD serial machine with an error of ±0.01 mm.

Results and discussion

A series of experiments was conducted to determine the regularity of the influence of the nozzle design, the stand-off between the nozzle and the workpiece, and the gauge pressure at the nozzle inlet on the size and nature of the change in the diameter of the assist gas jet and the amount of cutting pressure created by it on the surface of the workpiece. The main results are shown in Figs. 5-7. All experiments were repeated three times. The maximum variation of the obtained values did not exceed 3 %.

A detailed analysis of the obtained results showed the following. At $P_n = 0.5$ MPa (Fig. 5, curve 3), when the stand-off between the nozzle and the workpiece changes from 0.2 mm to 3 mm with a step of 0.2 mm when using a dual-channel nozzle, the diameter of the assist gas jet remains relatively stable. The changes are oscillatory with a slight downward trend. The slope coefficient of the approximating line (as a general estimate of the trend) is $\gamma = -0.062$ (Fig. 6, a). An increase in the overpressure in the nozzle to $P_n = 1$ MPa (Fig. 5, curve 4) already significantly affects the change in the diameter of the assist gas jet. An increase in diameter is observed compared to $P_n = 0.5$ MPa in the entire range of stand-offs. While maintaining the oscillatory nature of the changes, there is a clear tendency to increase the diameter with an increase in the stand-off s. The slope of the approximating line is $\gamma = 0.5$ (Fig. 6, b).

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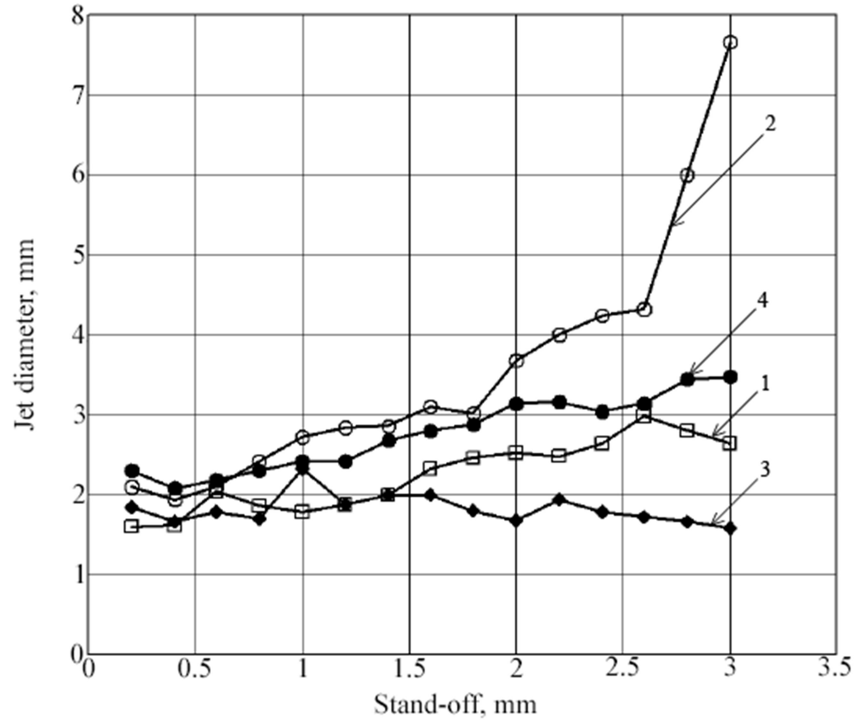

Figure 5. Change of the jet diameter in the contact area with the workpiece surface depending on the stand-off between the nozzle and the workpiece:

1 – single-channel nozzle, gauge pressure P_n = 0.5 MPa; 2 – single-channel nozzle, gauge pressure P_n = 1 MPa; 3 – dual-channel nozzle, gauge pressure P_n = 0.5 MPa; 4 – dual-channel nozzle, gauge pressure P_n = 1 MPa

As expected, the results obtained in the study of a single-channel nozzle under the same conditions differ from the dual-channel nozzle. At P_n = 0.5 MPa with stand-offs from 0.2 mm to 1.4 mm, the parameters of the jet diameter change are close to the results of the dual-channel nozzle. Subsequently, when the stand-offs increase from 1.4 mm to 3 mm, the single-channel nozzle forms significantly larger jet diameters (Fig. 5, curve 3). The slope of the approximating line is γ = 0.464 (Fig. 6, c).

When using a gauge pressure of P_n = 1 MPa in the range of stand-offs of 0.2 mm to 0.8 mm, the parameters of the change in jet diameter are close to the results of the dual-channel nozzle (Fig. 5, curve 4). When the stand-off changes from 0.8 mm to 1.8 mm, a relatively slight increase in the jet diameter is observed compared to the dual-channel nozzle. With an increase in the stand-off from 1.8 mm to 2.6, the excess already increases significantly, and the oscillatory nature of the change in the jet diameter disappears. From 2.6 mm to 3 mm, there is an abrupt linear increase in diameter (from 4.32 mm to 7.65 mm).

It can be stated that the flow practically "scatters". The slope coefficient of the approximating line is γ = 1.556 (Fig. 6, d). It is worth noting that the results obtained generally confirm the known solution to the problem of jet narrowing. The essence of the solution is to surround the central jet with a gas flow flowing from a slotted annular contour whose diameter is several millimeters larger than the diameter of the central jet. This led to the development of dual-channel nozzles. The component of the flow velocity from the annular contour is directed radially with respect to the nozzle axis and thus limits the expansion of the central jet.

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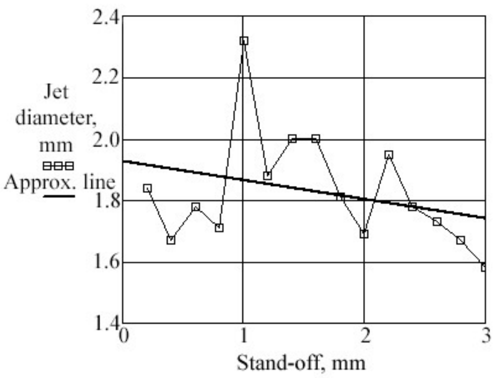
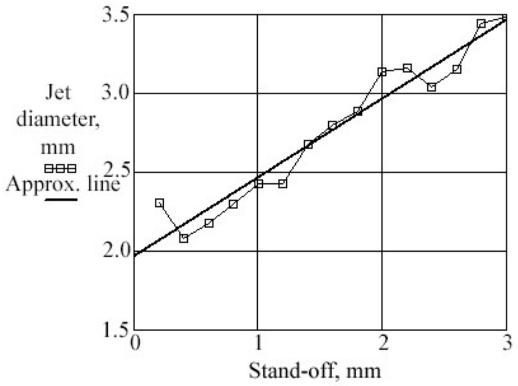
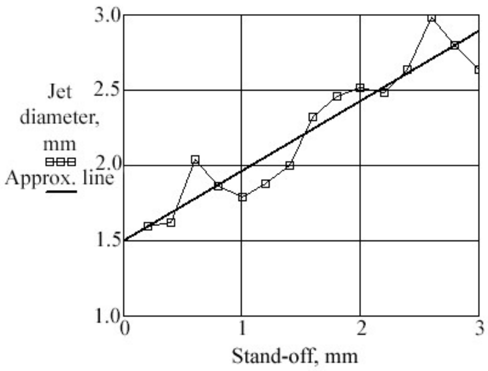


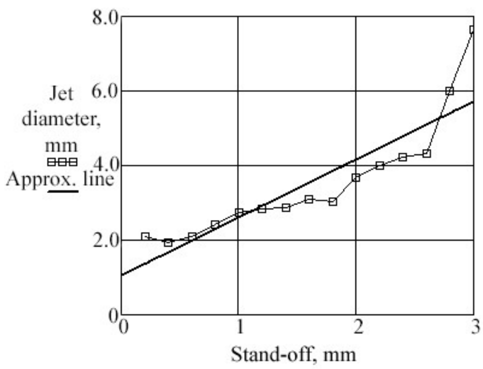
a (γ = -0,062)



b (γ = 0,5)



c (γ = 0,464)



d (γ = 1,556)

Figure 6. Approximating lines of graphs of changes of the jet diameter in the processing surface contact area depending on the gap between the nozzle and the part. Obtained using the Mathcad:
a – (dual-channel nozzle, P_n = 0.5 MPa); b – (dual-channel nozzle, P_n = 1 MPa);
c – (single-channel nozzle, P_n = 0.5 MPa); d – (single-channel nozzle, P_n = 1 MPa)

The obtained graphs of the assist gas pressure change are shown in Fig. 7. When using a single-channel nozzle and P_n = 0.5 MPa (Fig. 7, curve 1), when the stand-off changes from 0.2 mm to 1 mm, the cutting pressure of the assist gas increases oscillatingly and reaches a maximum at a stand-off of 1 mm (444 kPa). After that, it drops rather smoothly and oscillatingly. Thus, for a given nozzle with P_n = 0.5 MPa, a 1 mm stand-off is optimal in terms of maximum process productivity. There is a zone of relatively stable pressure at stand-offs of 0.8 mm – 1.2 mm (411 kPa – 444 kPa).

An increase in the overpressure in the nozzle to P_n = 1 MPa (Fig. 7, curve 2) leads to a local maximum of cutting pressure at a stand-off of 0.4 mm (686 kPa) with a sharp drop to 443 kPa at a stand-off of 0.6 mm. The second local extreme of the cutting pressure is observed at a stand-off of 0.8 mm (502 kPa). With a further increase of the stand-off, the cutting pressure drops oscillatingly. Moreover, at some stand-offs, the cutting pressure at P_n = 1 MPa is lower than at P_n = 0.5 MPa (s = 1 mm, P_n = 1 MPa – 409 kPa, P_n = 0.5 MPa – 444 kPa). Thus, when using this type of nozzle, increasing the gauge pressure from P_n = 0.5 MPa to P_n = 1 MPa will give a significant increase in cutting pressure only at stand-

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offs as close as possible to 0.4 mm (+320 kPa). But at such stand-offs, there is a risk of rapid clogging of the nozzle or damage to the protective glass of the optical head. In the range of 0.6 mm – 0.8 mm, an increase in the pressure at the nozzle inlet gives a significantly lower increase in cutting pressure (+105.5 kPa … +91 kPa). From the point of view of achieving maximum cutting performance, the use of this type of nozzle for stand-offs larger than 1 mm makes no sense.

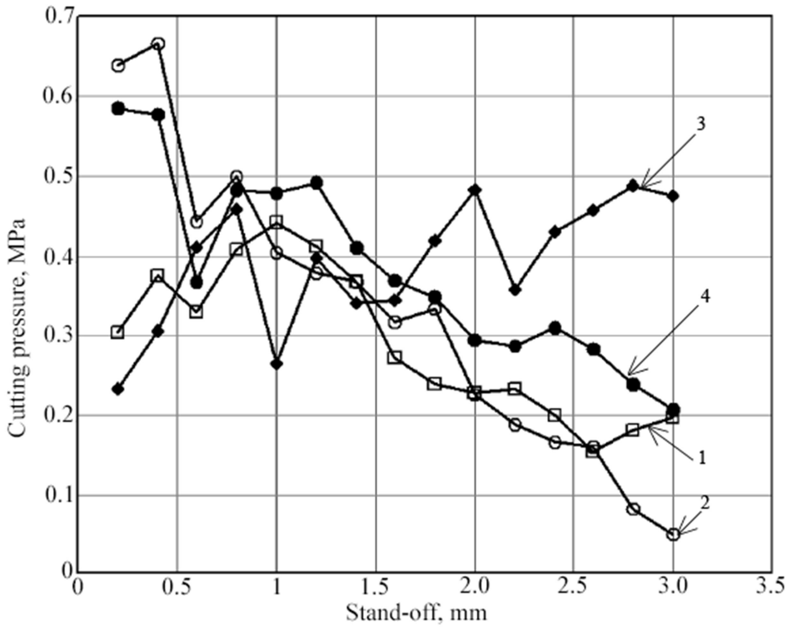

Figure 7. Change of cutting pressure on the surface of the workpiece depending on the stand-off between the nozzle and the workpiece:
1 – single-channel nozzle, gauge pressure P_n = 0.5 MPa; 2 – single-channel nozzle, gauge pressure P_n = 1 MPa; 3 – dual-channel nozzle, gauge pressure P_n = 0.5 MPa; 4 – dual-channel nozzle, gauge pressure P_n = 1 MPa

When using a dual-channel nozzle and P_n = 0.5 MPa (Fig. 7, curve 3), a close to linear increase in cutting pressure is observed when the stand-off changes from 0.2 mm to 0.8 mm with a local extremum at a stand-off of 0.8 mm (477 kPa). After that, at a stand-off of 1 mm, the cutting pressure drops sharply (267 kPa). With a further increase in the stand-off, the changes in cutting pressure are oscillatory in nature with an extreme at a stand-off of 2 mm (491 kPa). This is followed by a characteristic sharp drop in pressure at a stand-off of 2.2 mm (369 kPa), followed by a smooth increase to a maximum value at a stand-off of 2.8 mm (510 kPa). Moreover, a certain stability of the cutting pressure (465 kPa – 510 kPa) is observed over a relatively wide range of stand-offs from 2.6 mm to 3 mm. Based on the above, it is easy to conclude that when using this nozzle and an overpressure of P_n = 0.5 MPa, the condition for ensuring maximum process performance is cutting at stand-offs of 2 or 2.8 mm.

An increase in the overpressure in the dual-channel nozzle to P_n = 1 MPa (Fig. 7, curve 4), as in the case of a single-channel nozzle, gives a local maximum cutting pressure at stand-offs of 0.2 mm … 0.4 mm (598 kPa … 594 kPa), which is, however, lower than that for a single-channel nozzle. Then there is a pressure drop at the stand-off of 0.6 mm to 370 kPa.

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The achieved pressure value is lower than the corresponding value for a single-channel nozzle. At the stand-offs of 0.8 mm to 1.2 mm, a zone of sufficiently high, stable cutting pressure (483 kPa to 496 kPa) is observed. In the range of 1.2 mm – 3 mm stand-offs, there is a smooth oscillating decrease in cutting pressure without sharp extremes. Thus, when using this type of nozzle, doubling the overpressure at the nozzle inlet, as in the case of a single-channel nozzle, results in a significant increase in cutting pressure only at stand-offs of 0.2 mm - 0.4 mm, which are quite risky in terms of a high probability of damage to the nozzle or the protective glass of the optical head. The extremes of the cutting pressure at the stand-offs acceptable for trouble-free cutting at the excessive nozzle inlet pressures of P_n = 0.5 MPa and P_n = 1 MPa are practically the same.

To experimentally verify the results obtained, test samples of carbon steel with a thickness of 1 mm were cut on a serial LTS-PRO-6000-1530-LD machine from Aramis using a dual-channel nozzle with a diameter of 1.5 mm. The experiments determined the maximum straight cut speed with acceptable side surface quality (Fig. 8).

a b

Figure 8. Photographs of the side surface of test specimens made of carbon steel with a thickness of 1 mm:
a – radiation power N = 3 kW, cutting speed F = 28000 mm/min, overpressure P_n = 1 MPa, monitored stand-off s = 1.2 mm; b – radiation power N = 3 kW, cutting speed F = 24000 mm/min, overpressure P_n = 1 MPa, monitored stand-off s = 2 mm;

The data shown in Fig. 8 demonstrate a fairly good correlation between the cutting pressure of the stagnant gas jet (Fig. 7) and the maximum laser cutting speed. The absence of dross and obvious damage to the side of the cut surface was considered acceptable quality. A drop in the cutting pressure from 496 KPa (s = 1.2 mm) to 296 KPa (s = 2 mm) leads to a decrease in the maximum cutting speed from 28000 mm/min to 24000 mm/min. Visual analysis also shows a clear deterioration in the side surface roughness of the test samples. Thus, the data shown in Fig. 8 demonstrate a fairly good correlation between the cutting pressure of the stagnant gas jet (Fig. 7) and the maximum laser cutting speed and quality.

Conclusions

1. The developed methodology and a series of experimental studies made it possible for the first time to establish quantitative dependences of the diameter of the supersonic jet of the assisted gas (air) and the cutting pressure in the machining zone created by its stagnation on the surface of the part on the design of the nozzle, the stand-off between the nozzle and the part, and the pressure at the nozzle inlet.

2. The established numerical regularities of the dynamics of changes in the diameter of the supersonic assisting gas jet under conditions of gas-assisted laser cutting have shown that a dual-channel nozzle, compared to a single-channel one, significantly reduces the jet

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expansion over the entire range of changes in the studied parameters. These results are consistent with the data known in the literature.

3. The obtained array of experimental data showed a complex oscillatory nature of the change in cutting pressure depending on the stand-off size, individual for each nozzle design and the overpressure value at its inlet. In the range of stand-offs from 0.2 mm to 3 mm selected for the study, the differences in maximum and minimum cutting pressures exceeded 100 %. That is, with the traditional use of the existing range of serial nozzles, without the results obtained in the experiments, it is impossible to predict at the design stage of the technological process what kind of pressure is created by the jet of the assisting gas in the cutting zone under specific technological conditions. In practice, this makes it problematic to effectively design gas-assisted laser cutting processes for maximum productivity and reproducibility of cutting quality.

4. Experimental verification of the obtained results was carried out on a serial machine LTS-PRO-6000-1530-LD by Aramis during gas-assisted laser cutting with maximum process productivity. The verification showed a good correlation between the local stagnant pressure of the assisting gas jet and the maximum laser cutting speed and the quality of the side surface.

5. In the future, the use of the methodology proposed in this paper makes it relatively easy to obtain a set of graphs of changes in cutting pressure for each nozzle that is equipped with the machine. This will give an understanding of what kind of pressure the jet of assisting gas creates in the cutting zone under certain technological parameters of the process. Accordingly, it will be possible to more reliably ensure productive high-quality cutting at a particular technological installation and improve the level of process reproducibility.

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ЗАКОНОМІРНОСТІ ВПЛИВУ КОНСТРУКЦІЇ СОПЛА ТА ТЕХНОЛОГІЧНИХ ПАРАМЕТРІВ ГАЗОЛАЗЕРНОГО РІЗАННЯ НА ТИСК ГАЛЬМУВАННЯ АСИСТУЮЧОГО ГАЗУ

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Анотація. В роботі запропонована та реалізована методика експериментального вимірювання розмірів зони дії та величини тиску, який забезпечує видалення рідкої фази при газолазерному різанні і створюється потоком асистуючого газу на поверхні деталі. При проведенні досліджень на базі серійного верстата LTS-PRO-6000-1530-LD фірми Араміс в оптичній головці верстата встановлювалися серійні сопла (одноканальне та двоканальне) компанії Thermacut з вихідним діаметром 1,5 мм. В експериментах як асистуючий газ використовували повітря з манометричним тиском на вході в сопло 0,5 МПа та 1 МПа. Встановлено закономірності впливу конструкції сопла, зазору між соплом і деталлю та манометричного тиску на вході в сопло на зміни діаметра надзвукового струменя асистуючого газу та величину тиску, який він створює при гальмуванні на поверхні деталі, за технологічних умов газолазерного різання. Отриманий масив експериментальних даних показав, що традиційний підхід до використання існуючого спектра серійних сопел робить проблематичним ефективне проєктування процесів газолазерного різання максимальної продуктивності та відтворюваності якості різу. Це пов'язано зі складними явищами в надзвуковому струмені, які визначають високу чутливість величини тиску на поверхні деталі до змін геометрії сопла та технологічних параметрів процесу. В результаті немає розуміння, яку саме величину тиску створює струмінь асистуючого газу в зоні різання за тих чи інших технологічних параметрів процесу. Запропонована в роботі методика дозволяє відносно просто створити «паспорти» сопел, якими комплектується кожний верстат. Таким чином стає можливим урахування реальної величини поля асистуючого тиску в зоні різання при проєктуванні конкретного технологічного процесу. Відповідно, надійніше забезпечується продуктивне високоякісне різання на цій технологічній установці та покращується рівень відтворюваності процесу. Експериментальна верифікація продемонструвала досить добру кореляцію між локальним тиском гальмування асистуючого газового струменя та максимальною швидкістю лазерного різання і якістю різу.

Ключові слова: газолазерне різання, асистуючий газ, сопло, надзвуковий струмінь, оптоволоконний лазер.

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