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Effect of a gas-vortex stabilization method on the kinematic properties of the jet in metal-cutting plasmatoms

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Abstract. Various methods of gas-vortex stabilization in plasma cutting torches are investigated. The results of the study demonstrate the dependence of the angle of gas injection into the nozzle on the kinematic and kinetic characteristics of plasma jet and, consequently, on the cutting parameters. Increased radial velocity component at the swirler output provides better uniformity of the velocity distribution and kinetic properties of the jet in the affected zone of a cut metal. As a conclusion, it is recommended to use the suggested narrow-jet-plasma technology for cutting thin sheet metals.

1. Introduction

The main criteria of efficiency in the design of plasma torches for air-plasma cutting of metals are productivity, cutting quality and reliability of plasma equipment. High values of these indicators depend, first of all, on the operation of the gas-dynamic stabilization system. The efficiency of this system determines the high degree of heat input and kinetic properties of the plasma arc (jet), the durability of the cathode and nozzle of the plasma torch [1, 2]. In modern plasma torches for metal cutting, as a rule, a gas-vortex stabilization method is used. This method implies a tangential supply of plasma-forming gas (PFG) to the nozzle and additional compression of the plasma arc (jet) at the nozzle outlet by a vortex flow of stabilizing gas (in narrow-jet-plasma technology) [3, 4]. Tangentially twisted gas flow is formed in the vortex chambers (swirlers). The number, design and location of swirlers in the plasma torch appreciably affects the efficiency of metal cutting.

The authors' investigations [5] showed that the method of gas-vortex stabilization with the use of single-flow scheme of PFG supplying to the nozzle via a single swirler does not provide uniform distribution of gas flow over the cross section of the air-gas path (AGP) and in the nozzle channel of the plasma torch. This problem arises due to the asymmetrical position of the gas supply relatively to the expansion chamber located in front of the swirler and due to the limited size of the chamber. The uniformity coefficient of gas flow distribution can be raised by increasing the chamber size [5] or using a system of gas dynamic filters as additional obstacles in the expansion chamber [6]. However, this increases the complexity of manufacturing and the cost of the plasmatron. In this regard, it is necessary to investigate other possibilities of constructive improvement of the gas-vortex stabilization system of metal-cutting plasmatoms.



2. Research Methods

Two plasma torches for metal cutting, developed by the authors' group and manufactured by the Polygon OJSC (Yekaterinburg, Russia) were taken for the study:

- PMVR-5.3 – from the series of single-flow plasma torches PMVR-5 with the built-in stepwise gas-dynamic filter and increased productivity for operation at currents up to 200 A (Fig. 1);
- PMVR-9.1 – from the series of double-flow plasma torches PMVR-9 with the built-in gas-dynamic filter and a system of the plasma arc double compression (narrow-jet-plasma technology) (Fig. 2).



Figure 1. Plasma torch PMVR-5.3

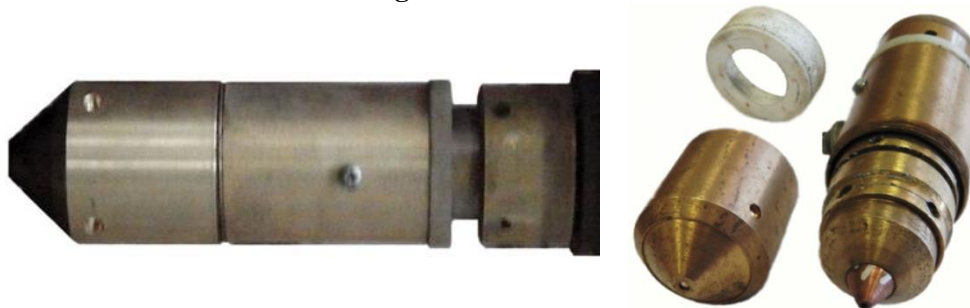


Figure 2. Plasma torch PMVR-9.1

The design of the AGP in plasmatron PMVR-5.3 is based on the principle of stepwise alignment of the PFG velocity across the channel section (i.e., the gas comes from 1 channel to 2, then from 2 to 4, etc.). The final element in this chain is the main swirler. The design of the plasma torch used commercially available cathode A-141 and a series of nozzles for A-141 with the outlet diameter from 1.4 to 1.8 mm. Initially, a serial swirler installed on the cathode A-141 (Fig. 3a) was used for testing the plasma torch. The peculiarity of this swirler is that the flow of PFG passing through the swirler is supplied tangentially to the cathode surface in a plane perpendicular to the cathode. Thus, the flow of PFG at the output of this swirler has only a radial component of the velocity (Fig. 3b).

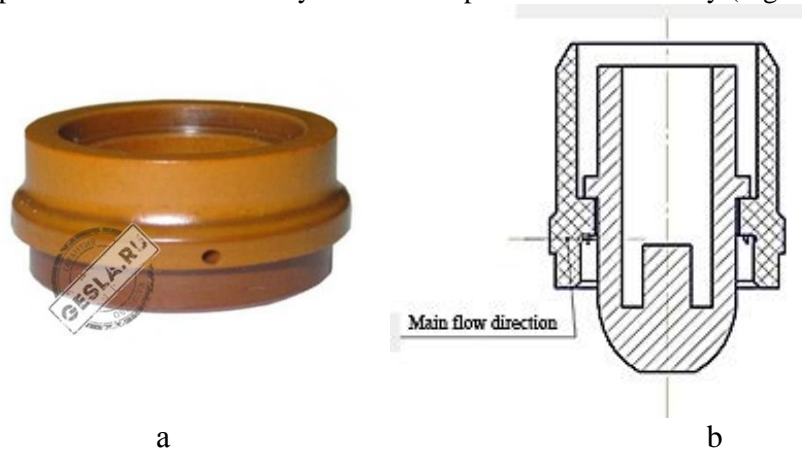


Figure 3. Serial swirler for the plasma torch PMVR-5.3:
a) visual appearance, b) application scheme

At the second stage an upgraded swirler instead of the serial swirler was used (Fig. 4a) for the testing of plasma torch. Distinctive features of the new swirler are the change in the number of holes (in accordance with the principle described above) and additional inclination of the holes to the axis of the plasma torch. The flow of PFG at the output of such swirler has not only a radial, but also an axial component of the flow velocity (Figs. 4b and 4c).

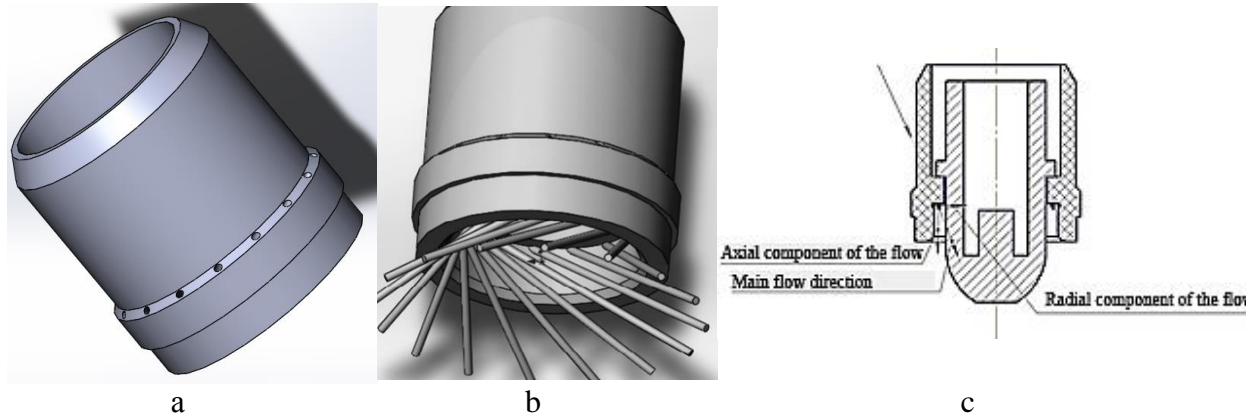


Figure 4. Upgraded swirler for the plasma torch PMVR-5.3:

a) visual appearance, b) direction of the PFG flow in the swirler, c) scheme of application.

The design of the plasma torch PMVR-9.1 is based on the separation of the PFG flow (plasma-forming and stabilizing flows) with separate gas supply to the nozzle. The plasma arc, formed by the main plasma-forming vortex flow, in this case, is further compressed (stabilized) due to an additional twisted gas at the outlet of the main nozzle of the plasma torch (Fig. 5a). The system of individual gas-vortex stabilization of the PFG flow uses the standard swirler of Hypertherm company. The swirler of secondary (stabilizing) flow has its own design (Fig. 5b).

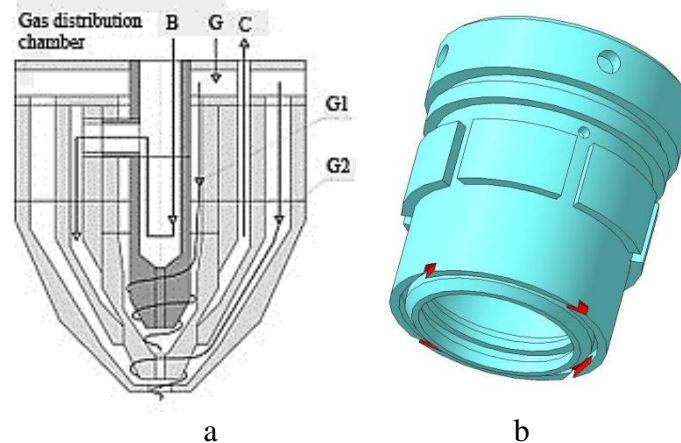


Figure 5. System of gas-vortex stabilization in plasma torch PMVR-9.1: a) scheme of AGP, B, C – inlet and outlet of the cooling system, G – gas supply into the gas distribution chamber, G1, G2 – plasma-forming and stabilizing flows; b) swirler of secondary (stabilizing) flow

The kinematic properties (local velocity) of the plasma jet were calculated to assess the effect of various methods of gas-vortex stabilization on the efficiency of the plasma torches. The studies were performed in the FlowWorks application of the SolidWorks software. They were based on a simulation of the gas flow through the channels of the plasma torch and in the area of its expiration. Technical passport data of such plasma torches for the mass flow of gas (common value is 0.011 kg/s) were used as initial data. Environmental parameters with normal atmospheric pressure were used at the

outlet of the plasma torch nozzle. In order to abstract from the thermodynamic effects, the calculation was carried out for a cold gas jet in disregard of the heating of the gas and the walls of the AGP channels by the plasma arc. The velocity was calculated at different distances from the axis of the nozzle channel and the cathode section of the plasma torch. The calculations were made along the lines parallel to the axis within the cylindrical region limited by the diameter of the nozzle channel (Fig. 6).

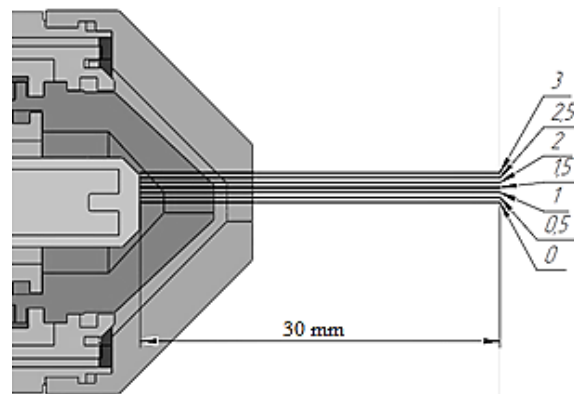


Figure 6. Calculation scheme for determination of kinematic characteristics of jet for the plasma torch PMVR-5.3

3 statistical parameters were used to analyze the flow rates V distribution:

1. Scope of variation $R = V_{\max} - V_{\min}$,
2. Ratio of variation $L = V_{\max} / V_{\min}$,
3. Coefficient of variation $F = S / (\bar{V})$, where S is dispersion of V , \bar{V} is average flow rate.

The combination of these parameters allows comparing the characteristics of flows both from the point of view on the kinetic properties and with regard to the uniformity of the velocity distribution in the cross section of the jet.

3. Results and Discussion

The results of the velocities calculation for different methods of gas-vortex stabilization in single- and double-flow plasma torches are demonstrated in Fig. 7. The analysis of the presented images allows drawing a conclusion about the differences in the velocity distribution, which determines the shape, length, kinematic and energy parameters of the plasma jet.

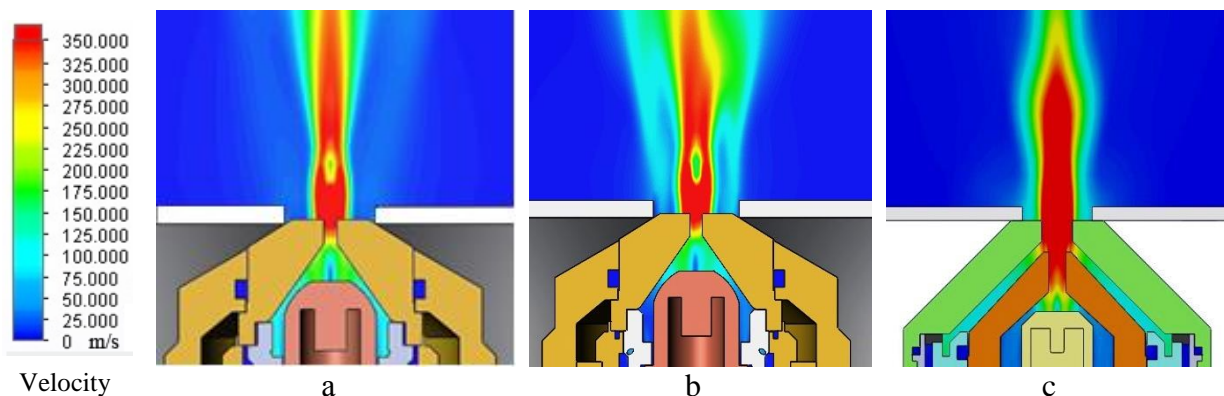


Figure 7. Velocity distribution in the jet of plasma torches: a) PMVR-5.3 with a serial swirler, b) PMVR-5.3 with the new swirler, c) PMVR-9.1 (double nozzle)

Figures 8, 9 and 10 demonstrate the results of the velocity calculation, executed in accordance with the scheme shown in Fig. 6 (for the upper axisymmetric part of the computational domain). Attention should be paid to the geometry of the nozzle, which determines the distance from the cathode plane to the nozzle section about 7 mm.

The analysis of the velocity distributions presented in Figs. 8 and 9 allows concluding about the effect of the new swirler applied in the PMVR-5.3 plasma torch on the kinematic properties of the jet. The nonuniformity of the velocity distribution along the channel section becomes significantly less expressed as it moves away from the jet expiration plane. In the jet of the plasma torch PMVR-5.3 with the new swirler, a smaller dispersion of velocities is also observed at a maximum estimated distance compared to the jet of plasma torch PMVR-5.3 with a serial swirler. The maximum velocities are approximately equal, and the average cross-section velocities have higher values in the jet of the PMVR-5.3 plasma torch with a new swirler. In fact, this indicates the preservation of higher energy properties over a larger range of plasma jet lengths, which, in turn, should have a positive effect on the current-voltage characteristics of the arc and its ability to cut metal of greater thickness at an increased speed.

Data calculations for the double-flow plasmatron PMVR-9.1 (Fig. 9) indicate a significantly more uniform distribution of velocities in the jet, both in the plane of expiration and at a distance from this plane. However, kinematic and energy properties of the jet, determined by the maximum and average velocity values, are maintained at a shorter (less than 25 mm) distance than in the jets generated by the single-flow plasmatron PMVR-5.3. This is also evidenced by the comparative graphs (Fig. 11). The last factor determines not only the technological conditions for cutting by this plasma torch, but also affects the acoustic properties of the jet. The size of the acoustic core of the jet with maximum velocities, as known [7], determines the level of noise emission, so the reduction of the core length should have a positive effect on the acoustic safety of this technology.

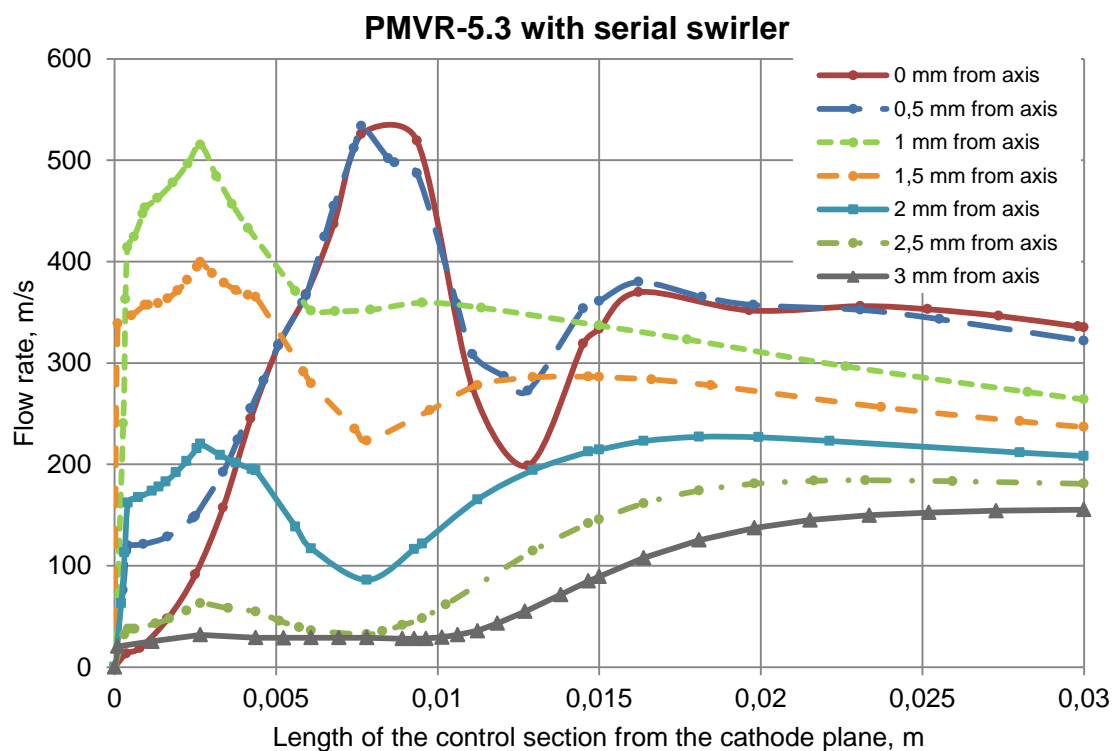


Figure 8. Velocity distribution in the jet of plasma torch PMVR-5.3 with serial swirler

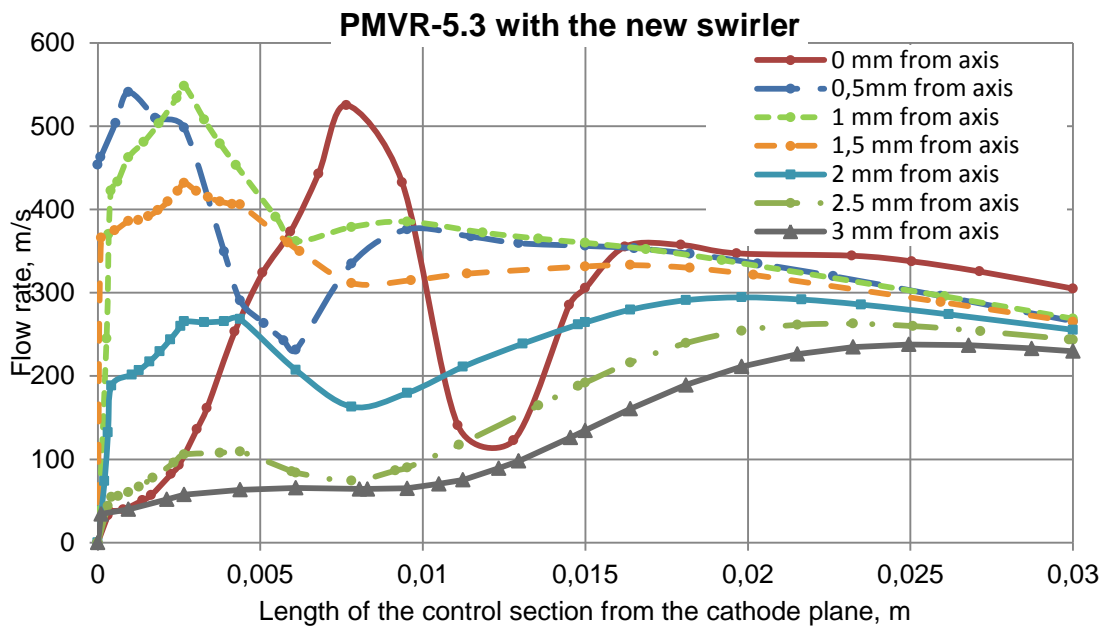


Figure 9. Velocity distribution in the jet of plasma torch PMVR-5.3 with the new swirler

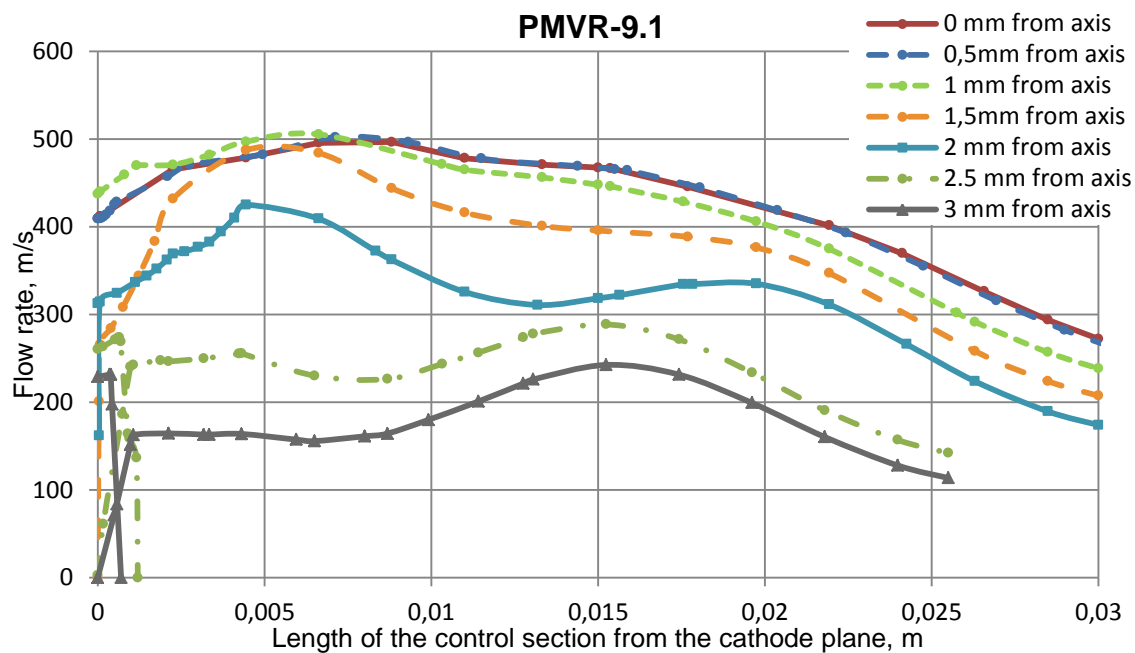


Figure 10. Velocity distribution in the jet of plasma torch PMVR-9.1

Fig. 12 shows the velocity distribution around the calculated cross section of the jet, which, in general, confirms earlier conclusions. Additional compression of the main PFG in the plasma torch PMVR-9.1 can significantly reduce nonuniformity of the velocity distribution in the plasma torch PMVR-5.3, arising on the nozzle section due to the disruption of the sharply expanding flow. In addition, the jet of the plasma torch PMVR-9.1 has higher kinetic properties (higher top speed) than the jet of the plasma torch PMVR-5.3. However, such advantages are observed only within a distance of 15-20 mm from the cathode section. At large distances, the PMVR-5.3 plasma torch with a new swirler has the higher indices of uniformity and kinetic properties, which is confirmed by the graphs of

statistical distributions of kinematic characteristics (Fig. 13). The growth of these indicators, in turn, should affect the increase in productivity and quality of cutting.

The last conclusion is confirmed by the data obtained in the process of plasma torch PMVR-5.3 cutting. The maximum cutting speed for 10-mm thick 09G2S steel plates at a current of 90 A was not more than 1.1-1.2 m/min. The use of the upgraded swirler increased the maximum cutting speed up to 1.5-1.6 m/min.

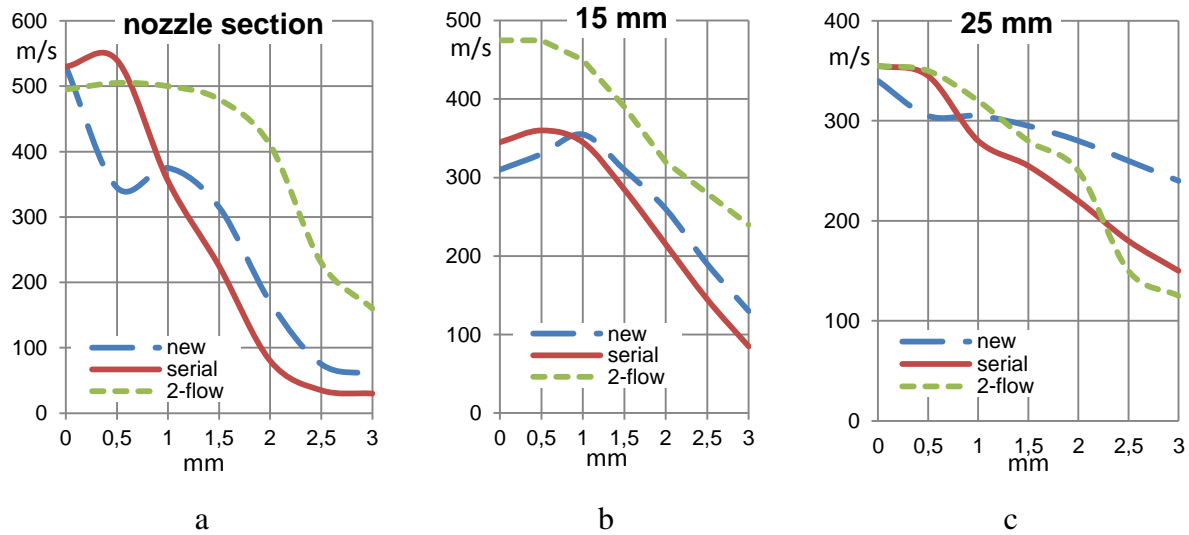


Figure 11. The velocity distribution over the cross section of the jet depending on the distance from the nozzle output of the plasma torch (PMVR-5.3 with serial and new swirlers and 2-flow PMVR-9.1)

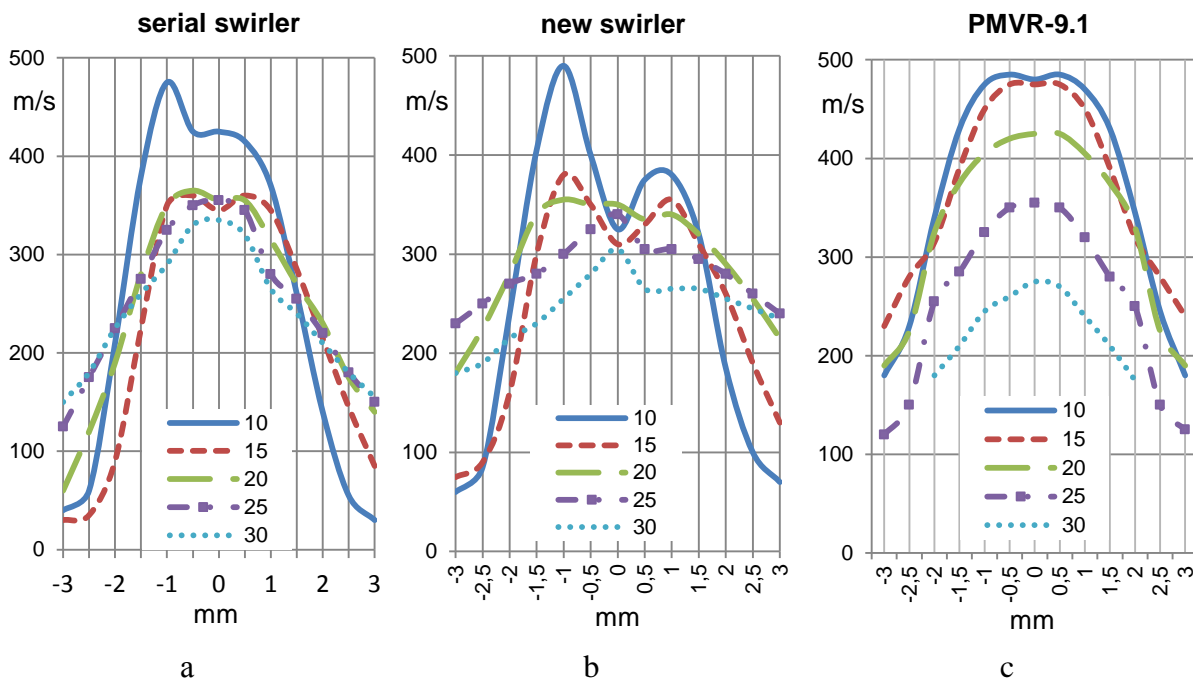


Figure 12. The velocity distribution over the cross section of the jet depending on the distance from the nozzle output of the plasma torch (PMVR-5.3 with serial and new swirlers and 2-flow PMVR-9.1)

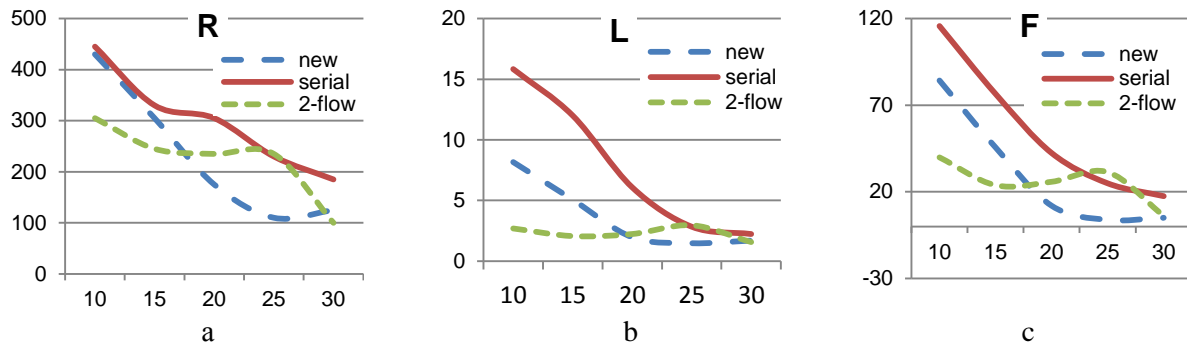


Figure 13. Statistical distributions of kinematic characteristics depending on the distance from the plasma torch nozzle output (PMVR-5.3 with serial and new swirlers and 2-flow PMVR-9.1): a) scope of variation R, b) ratio of variation L, c) coefficient of variation F

4. Conclusions

The results of the study demonstrate the dependence of the angle of PFG injection into the nozzle on the kinematic and kinetic characteristics of plasma jet and, consequently, the cutting parameters. This conclusion provides the basis for further research to determine the optimal angle of PFG injection into the nozzle and its impact on the productivity, cutting quality and durability of the plasma torch. As a conclusion, it is recommended to use the suggested narrow-jet-plasma technology for cutting thin sheet metals.

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