Development of a compact plasma torch design for welding and surfacing

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Abstract. The article discusses the development of the design of the plasma torch used for welding and surfacing, the relevance of the plasma type of welding, the stages of work necessary to develop this design, modeling the flow of protective and working gas.

1. Introduction

Relevance of work: plasma technologies have long established themselves in welding operations [1, 2], however, today there is a decline in research activity and the introduction of new developments in this field. Plasma torch is one of the fundamental components of plasma welding; therefore, the development of new torches will allow increasing the efficiency of indicators such as productivity, convenience and quality of welding.

Plasma torches with direct polarity current are used everywhere and are the determining components of any plasma process [3]. One of the successful examples of the application of plasma processes is plasma surfacing, which is used to create special and protective coatings [4]. It is also possible to use plasma surfacing in additive manufacturing.

A plasma-forming gas flows around the electrode inside the burner. The ignition of the pilot arc usually occurs due to a high voltage pulse. As a result of the formation of an electric arc, the gas is heated to a temperature at which its ionization occurs. Moreover, around the cooled surface of the tip, it remains cold and non-conductive. A narrowing of the plasma torch occurs due to it. In addition to these factors, the diameter of the tip through which the arc exits also affects the quality of the formed surfacing and protective coatings.

Plasma torches, which are used for manual welding, should also be as convenient as possible for the welder. Based on this, the design of a compact plasma torch will be proposed in this study, which can be used for both manual and automatic welding.

Purpose of work: development of a compact plasma torch design for welding and surfacing using low and medium current values.

Task of work: development of a plasma torch is a multi-component task, which includes both the study and development of design documentation, followed by modeling of the selected solutions, and the manufacture of prototypes, and conducting real experiments. At this stage, it is necessary to develop the design of the plasma torch, reflected in the drawings and modeling the flow of protective and working gas. Due to the modeling of structural elements where gas is used, it becomes possible to improve the design without going to the stage of prototype manufacturing and conducting real experiments.
2. Analysis of existing designs of plasma torches for welding and surfacing

Plasmatrons for welding and surfacing, using inert gases as a protective and working gas, are now quite rare. In Russia, at the moment, almost no research is being carried out in the development of new plasma torches for welding, despite the fact that plasma welding has a high productivity, as well as the heat-affected zone and the welding seam is smaller compared to other manual welding methods.

The following models were considered as similar plasmatron designs:

A plasmatron is considered in [5], figure 1, which has small mass and size characteristics and can be used as an ignition device, or in plasma processing of materials in domestic conditions.

The following differences can be distinguished when comparing this design with the proposed one: since the plasmatron [5] is offered for domestic use, it did not provide for the protection of the weld using shielding gas, which affects the obtained characteristics of the weld. Air is used as a working gas. The cathode is a copper electrode. The possibility of water cooling of the anode is not provided, which reduces its service life. There is no possibility of quick electrode replacement.

![Figure 1. A section along the longitudinal axis of the plasmatron device [5].](image-url)
The objective of the invention [6] was the creation of a small plasma torch for manual welding with direct current, figure 2, creating a stable electric arc burning between the electrode and the workpiece. In the design [6] there is no possibility of using water cooling of the anode. The use of a copper electrode is assumed as a cathode. Also, the type of method for creating plasma acts as a difference; in this work, a plasmatron with the possibility of direct and indirect connection is presented. There is no possibility of quick electrode replacement.

![Figure 2](image_url)

**Figure 2.** Section along the longitudinal axis of the plasmatron device [6].

The design of the plasmatron, figure 3, having reduced overall dimensions, with the existing water-cooling system, in contrast to the aforementioned, is presented in [7]. The main difference of the proposed device from the design [7] is the significant simplicity of the design. The design lacks the ability to quickly replace the electrode. The plasma torch [7] also uses a copper electrode as a cathode.

3. **Requirements for the developed design of the plasma torch**

The plasmatron is structurally quite a complex device. The plasma torch is such a complex design due to the content of elements operating under high temperature loads, requiring intensive cooling during welding / surfacing, as well as the influence of the shape of the plasma-forming unit on the protective properties.

The plasma torch must meet the following criteria:

- Elements subject to greater thermal effects should have maximum thermal conductivity;
- Presence of a sufficient level of structural cooling achieved by water and gas;
- Plasma forming unit should have the maximum possible volume with a constant surface area;
- Electrode must be firmly fixed and centered using the electrode holder;
- Lack of double arcing;
- Operation of the structure at low (microplasma welding) and medium currents;
- Ability to replace the electrode quickly and easily;
- Compliance with certain overall dimensions;
- Use for welding and surfacing.
4. Developed plasma torch design
Initially, a sketch of the plasmatron was developed, according to which the design was developed, figure 4. The requirements that the plasmatron must meet were taken into account, and, as the main task, the possibility of reducing the overall structure was considered.

Figure 3. Drawings of the plasma torch assembly [7].
Figure 4. Sketch of the developed plasma torch with maximum overall dimensions.

The plasma torch consists of a tungsten electrode 1, which is tightly fixed due to the threaded connection of the clamping screw 2 and the electrode holder assembly 3. In the nozzle channel 4, in which the channels for the protective gas 5, working gas 10 and water cooling 9 are located, the electrode holder assembly 3 is fixed. An adapter for tip 6 and a protective nozzle 7 are attached to the nozzle channel 4. A plasma is formed in the region of the tip 8.

5. Modeling of structural units of gas outflow in a plasmatron

After developing the sketch and solid-state structural elements, the task arose to understand how the protective and working gas will behave in the channels designed for them. “Ansys” engineering analysis and numerical simulation software was used for this task.

Shielding gas outflow modeling was performed to improve the geometry of the gas channel, figure 5. As a result, it was possible to achieve a more uniform distribution of the gas flowing around the structural units that need to be cooled, figure 6. Also, thanks to the shielding gas, better weld protection during welding and surfacing is achieved.

Figure 5. Simulated shielding gas supply unit.
Figure 6. Channel simulation results for shielding gas $a), c)$ – the first sample is the most successful; $b), d)$ – the second sample.

As a result of modeling the working gas unit, figure 7, various results were obtained, figure 8. It was proved that when the gas moves through the channels, turbulences are formed in the region of its collision with the electrode, which should be minimized, since the flow rate decreases. In the vicinity of the gas outlet from the plasma torch, it is possible to use various tip designs, however, we need the gas flow to be laminar, since we use the plasmatron for welding and surfacing, and not for cutting. In this case, the correct tip geometry necessary for the formation of a plasma flow should be preserved.

Figure 7. Unit for modeling the flow of working gas.
6. Results

The developed 3D model of the plasma torch was designed using the “Compass 3D” program. It becomes possible to conduct surface and solid modeling of 3D objects using this software. Figure 9 shows a 3D model of the assembly of a plasma torch in isometric projection.

This model is noteworthy for its geometric characteristics, due to the reduction of some elements, as well as combining certain parts together; it was possible to achieve the minimum dimensions of the structure. This allows reducing the basic cost of the plasma torch, while maintaining quality at a high level, since it is supposed to use argon as a protective and working gas in this design. Also, the level of comfort during the work process increases by reducing the total weight acting on the welder, when using this model for manual welding. Water cooling was provided in the tip design to avoid overheating of components.

Figure 8. Channel simulation results for working gas

6) – the first sample; b) – second sample.

Figure 9. 3D model of a plasma torch.
7. Conclusion
As a result of the work, the design of a compact plasma torch for welding and surfacing was developed. This plasmatron has a number of promising advantages for further modernization. Data were also obtained on the influence of the geometric characteristics of the channels for the protective and working gas. It is possible to achieve a more uniform distribution with the right direction of the shielding gas channel. Also, it is possible to get a laminar flow without violating the geometry of the tip when changing the channel for the working gas. The next stage in the development of a plasma torch will include the manufacture of prototypes of plasma torches and laboratory welding experiments.

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