تطوير البلازما تـــــرون بإضافة مقاطع كاثود مقسمة مع السماح بتطبيق ضغط إضافي

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الملخص العربي :

تظهر نتائج المحاكاة العددية لبلازماترون مع عقدة الكاثود المقطعة والتي أظهرت أنه تحت ضغط منفذ البلازما ، ، يزيد الضغط الجزئي للغازات المحتوية على الأكسجين في الفضاء الكاثودي بشكل كبير، مما قد يؤثر سلبا على خصائص الانبعاثات من مادة الكاثود.

ولذلك، فإن عدم مراعاة المقاومة الهيدروليكية للأنظمة التي هي جزء من المجمع الذي تم دمج البلازما، يمكن أن يؤدي إلى عواقب سلبية، وهي تآكل كبير وانخفاض عمر النظام ككل. ولذلك، فإن مستوى الضغط الزائد في منفذ البلازما هي واحدة من المعلمات الرئيسية في تصميم مولدات البلازما. وفي المقابل، تبين أنه في التصاميم التقليدية الحالية لمولدات البلازما لا يوجد مورد طاقة مطلوب لتغيير خصائص التدفق.

وبالنسبة لعملية مستقرة في ظروف الضغط الزائد، اقتُرح استخدام بلازماترون من طراز ف-13، الذي أظهر أنه تم التوصل إلى حدود التصميم الحالية فيما يتعلق بالكمال في المعلمات الهندسية لتجميع الكاثود. إن تقليل الآثار الضارة للغازات المحتوية على الأكسجين لا يمكن تحقيقه إلا بزيادة تدفق غاز التدريع أو باستخدام مواد الكاثود ذات عتبة تسمم أعلى. وباستخدام الأساليب المقترحة في هذا العمل، أجريت حسابات تصميم البلازماترون لمشاكل تغوي المواد الخام مع إمكانية وجود نطاق أوسع من تنظيم بارامترات الحمولة الحالية وتدفق الغازات الواقية والغازات التي تشكل البلازما. بالمقارنة مع الهيكل الأساسي ، تم زيادة تجميع الأنود وقطر الكاثود ، وزادت أقسام العرض من الغازات الواقية والبلازما ، تم تغيير تصميم إدراج القطب وفي المرحلة الأولية، كان معدل تدفق غاز التدريع 0.001 كجم/س، وكان الغاز الذي يشكل البلازما 0.04 كجم/س.

وقد استخدمت شبكة سداسية لأخذ عينات من المنطقة الحسابية المغلقة في تجويف نموذج البلازماترون، بما في ذلك تحديد الطبقة السطحية والمناطق الخاصة من المداخل ومنافذ.

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DEVELOPMENT OF A PLASMATRON WITH A SECTIONED CATHODE ASSEMBLY WITH ALLOWANCE FOR EXCESS PRESSURE

Abstract :

The results of numerical simulation of a plasmatron with a sectioned cathode node are shown, which showed that under the pressure of the plasmatron outlet, the partial pressure of oxygen-containing gases in the cathodic space significantly increases, which may adversely affect the emission characteristics of the cathode material.

Therefore, failure to take into account the hydraulic resistance of the systems that are part of the complex into which the plasmatron is integrated, can lead to negative consequences, namely, significant erosion and reduced system life as a whole. Therefore, the level of excess pressure at the outlet of the plasmatron is one of the key parameters in the design of the plasma generators. In turn, it is shown that in existing traditional designs of plasma generators there is no power resource required to change the flow characteristics.

For stable operation under conditions of excess pressure, it was proposed to use a P-13 type plasmatron, which showed that within the existing design limits were reached regarding the perfection of the geometric parameters of the cathode assembly. Reducing the harmful effects of oxygen-containing gases is only possible by increasing the flow of shielding gas or by using cathode materials with a higher poisoning threshold. Using the methods proposed in this work, design calculations of the plasmatron were made for the problems of gasification of raw materials with the possibility of a wider range of regulation of the parameters of the current load and the flow of protective and plasma-forming gases. Compared to the base structure, the anode assembly and cathode diameter were increased, the sections of supply of protective and plasma gases were increased, the design of the electrode

insert was changed. At the initial stage, the flow rate of the shielding gas was 0.001 kg/s, and the plasma-forming gas was 0.04 kg/s.

A hexagonal grid was used to sample the computational region enclosed in the cavity of the plasmatron model, including the determination of the surface layer and special regions of inlets and outlets.

Keywords: electric arc plasma generator, plasmatron, computer-aided design, cathode assembly, overpressure.

Introduction

The widespread usage of plasma technologies in various industries dictates the need to improve the calculation methods of plasma equipment, especially in the processes of plasma gasification of raw materials [1-3]. The key features of processes taking place in plasmatrons significantly complicates the experimental production of the parameters requited for the design. Therefore, it is an important task to create and improve the methods for calculating the parameters of plasmatrons.

Problem Statement

In the paper [4] it was shown that failure to take into account the hydraulic resistance of the systems that are part of the complex into which the plasmatron is integrated, can lead to negative consequences, namely, significant erosion and reduced system life as a whole. Therefore, the level of excess pressure at the outlet of the plasmatron is one of the key parameters in the design of the plasma generators. In turn, in the papers [4,5], it is shown that in existing traditional designs of plasma generators there is no power resource required to change the flow characteristics. Therefore, for stable operation under conditions of excess pressure, it was proposed to use a P-13 type plasmatron, the design of which was proposed in the papers [4,5], but the studies made in the paper [5] showed that within the existing design limits were reached regarding the perfection of the geometric parameters of the cathode assembly. Reducing the harmful effects of oxygen-containing gases is possible only by increasing the consumption of shielding gas or by using of cathode materials with a higher poisoning threshold, such as compositions developed in the paper [7]. Using the methods proposed in this work, design calculations of the plasmatron were made for the problems of gasification of raw materials with the possibility of a wider range of regulation of the parameters of the current load and the flow of protective and plasma-forming gases.

Research Results

Compared to the base structure, the anode assembly and cathode diameter were increased, the sections of supply of protective and plasma gases were increased, the design of the electrode insert was changed. At the initial stage, the flow rate of the shielding gas was 0.001 kg/s, and the plasma-forming gas was 0.04 kg/s.

A hexagonal grid was used to sample the computational region enclosed in the cavity of the plasmatron model, including the determination of the surface layer and special regions of inlets and outlets (Fig. 2).

The design problem was solved in several stages. At the first stage, only the gas space was considered in order to determine the velocity and temperature fields, taking into account the effect of excess pressure. The atmosphere composition near the emitter surface and comparison of values of the partial air pressure with the critical value for the emission material of the cathode were also determined.

As a result of the primary analysis of the velocity distribution in the cathode space of the base structure (Fig. 3), it was detected the zones of vortex structures towards the cathode, which disturbed the pattern of currents in the cathode space and could lead to poisoning of the cathode material.

To study the gas-dynamic parameters of the plasmatron the following mathematical model(1) – (7) Was used.

$$\frac{\partial n_z}{\partial t} = D\frac{\partial^2 n_{zr}}{\partial z^2} + V_{zr}\frac{\partial n_{zr}}{\partial z} \quad (1)$$

Is the concentration of air molecules (atoms) as a function of coordinates ; D is the coefficient of mutual molecular diffusion of air in argon.

$$n_e\left(\frac{n_r}{n_{r-1}}\right) = 2\frac{g_r}{g_{r-1}}\left(\frac{2\pi m_e kT_e}{h^2}\right)^{3/2} exp\left(-\frac{U_I - \Delta U_I}{kT_e}\right) \quad (2)$$

$$\frac{\partial \rho}{\partial t} + \nabla\cdot(\rho u) = 0, \quad (3)$$

$$\frac{\partial(\rho u)}{\partial t} + \nabla\cdot(\rho u \times u) = -\nabla P - \nabla\cdot\tau + j \times B + qE \quad (4)$$

The tension of the electric and magnetic fields is from Maxwell's family:

$$div\, D = \rho_e, \quad div\, B = 0, \quad rot\, E = -\frac{\partial B}{\partial t}, \quad rot\, H = j \quad (5)$$

e is the total charge; B - magnetic induction; E is the electric field strength; H is the magnetic field strength; j is the current density, Te is the electron temperature. To determine the temperature, it is necessary to match the balance of energy:

$$\frac{\partial(\rho H)}{\partial t}-\frac{\partial p}{\partial t}+\nabla\cdot(\rho u H)=\nabla(\lambda\nabla T)+\nabla\cdot(u\cdot\tau)+u\cdot S_{м}+\frac{j^2}{\sigma}-U_{rad}\cdot(6)$$

The total radiation of argon plasma was modeled as a negative volumetric source. To determine the dependence of the total radiation on temperature, the calculation technique presented in [11] was used:

$$U_{rad}=1.14e^{-40}\sqrt{T}\,exp\left(-\frac{\Delta E_i}{kT}\right)n_e\left[n_i\,exp\left(\frac{h\nu}{kT}+4n_{2i}\,exp\left(\frac{h\nu^+}{kT}\right)\right)\right],(7)$$

где $h\nu=2.85e\nu$; $h\nu^+=8.2e\nu$; $\Delta E_i=\frac{e^2}{4\pi\varepsilon_0 R_D}$ – lowering the ionization

potential,

; $R_D=\frac{\varepsilon_0 k T_e T_a}{e^2 n_e(T_e+T_a)}$ – Debye radius

In order to prevent the occurrence of reverse flows and vortex structures in the near-cathode space, an adjustment was made to the geometry of the flow part of the plasma generator model – it was increased the radius of curvature at the anode part and it was made a conical channel of the intermediate section. To close the return air flow, the diameter of the intermediate section was reduced, and the channel itself was made with a cone, the distance between the sections was reduced (Fig. 4).

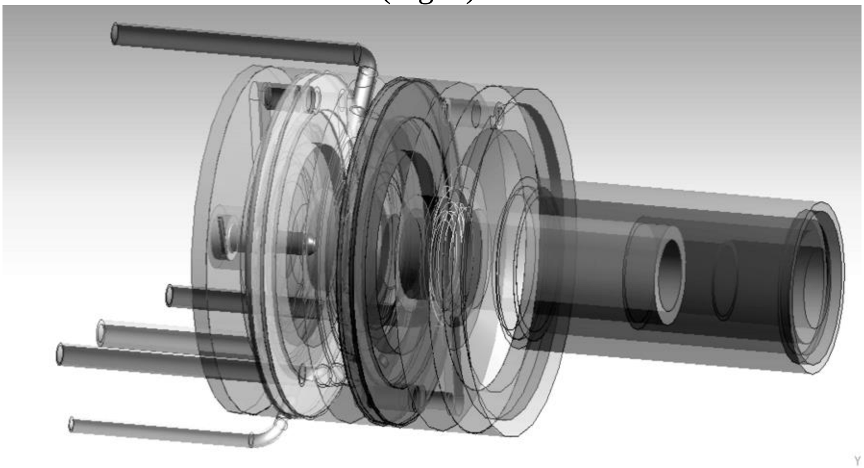

Figure 1 – Geometry of the modernized plasmatron[3,4]

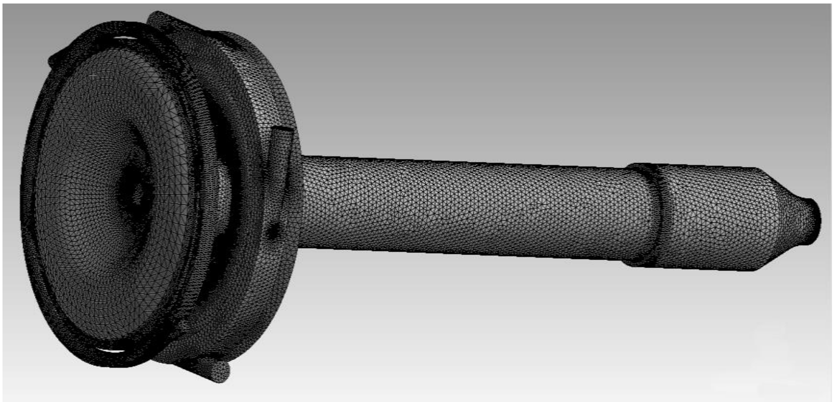

Figure 2 – Reference grid of the model[4]

Modification of the intermediate section allowed to control the flow of plasma-forming gas in the range from 0.03 to 0.05 kg/s and managed to achieve a symmetrical flow in the channel of the plasma generator (Fig. 5). Then the calculated temperature distribution in the plasma torch channel (Fig. 6) was exported as the initial conditions for the second stage. The purpose of the second stage was to calculate the heat transfer from the heated gas to the copper walls of the plasmatron housing. For this purpose, the following computational regions were identified – solid, gas (flowing part) with the path of cooled liquid.

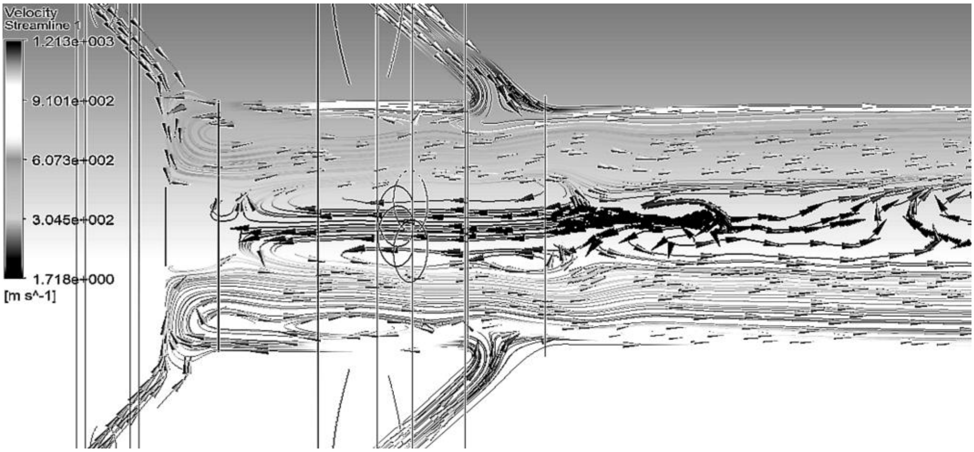

Figure 3 – Velocity distribution in the cathode space[4]

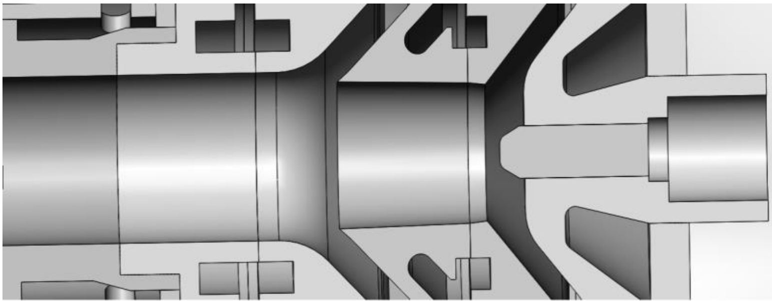

Figure 4 – Modified geometry of the plasmatron flowing part [5]

As a result of the calculation of the related problem, the temperature distribution on the wall of the plasmatron housing was calculated (Fig. 7) and passed on to calculate the efficiency of the cooled path. The calculation was performed for the case with a water consumption in the rate of 0.5 kg/s.

As shown in Fig. 8, the most temperature-loaded structural elements are the cathode and anode mandrels, from which it follows that to increase the efficiency of the cooling system it is necessary to cool the cathode separately from the other design of the plasmatron. In the anode part of the plasmatron, there are stagnant zones and zones of weak circulation, i.e. potential places for the burns of the anode walls.

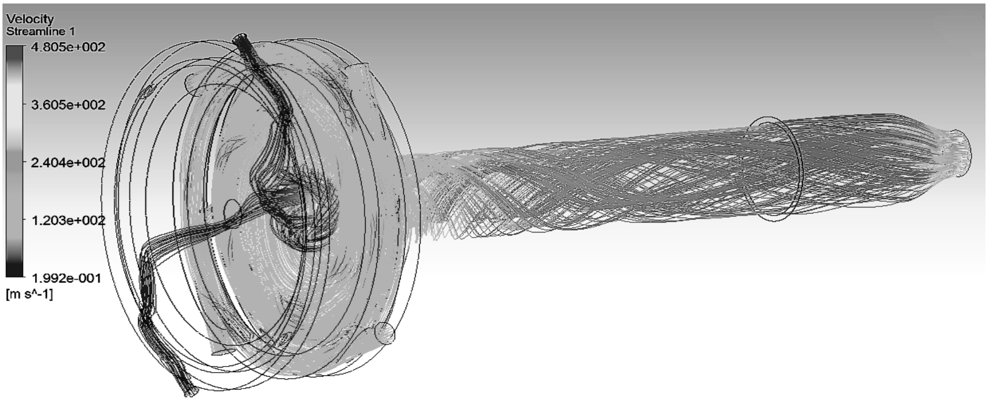

Figure 5 – General picture of the flow (current lines)[4]

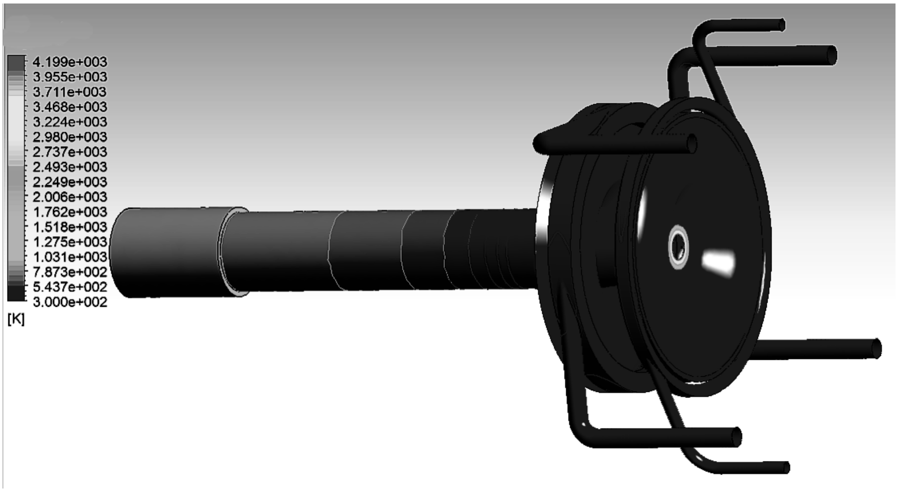

Figure 6 – Temperature distribution on the wall of the plasma torch channel [4]

As a result of the initial analysis of the cooling system, it was decided to improve it by dividing it into a cooling system of the cathode assembly and the cooling system of the housing and anode to increase overall efficiency and prevent short circuits in case of burns (Fig. 9). The path of the anode assembly was also improved to prevent the occurrence of stagnant zones.

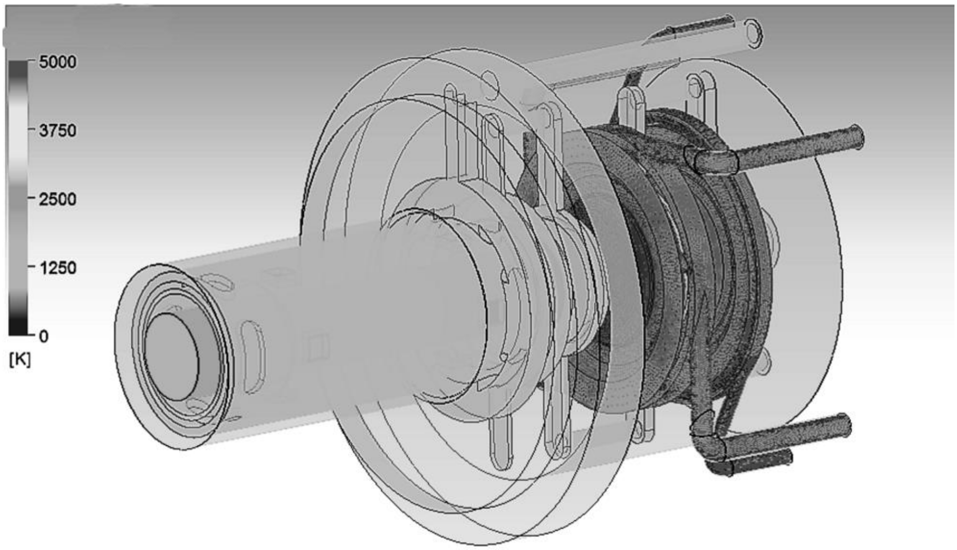

Figure 7 – Temperature distribution on the wall of the plasma torch housing[8.9]

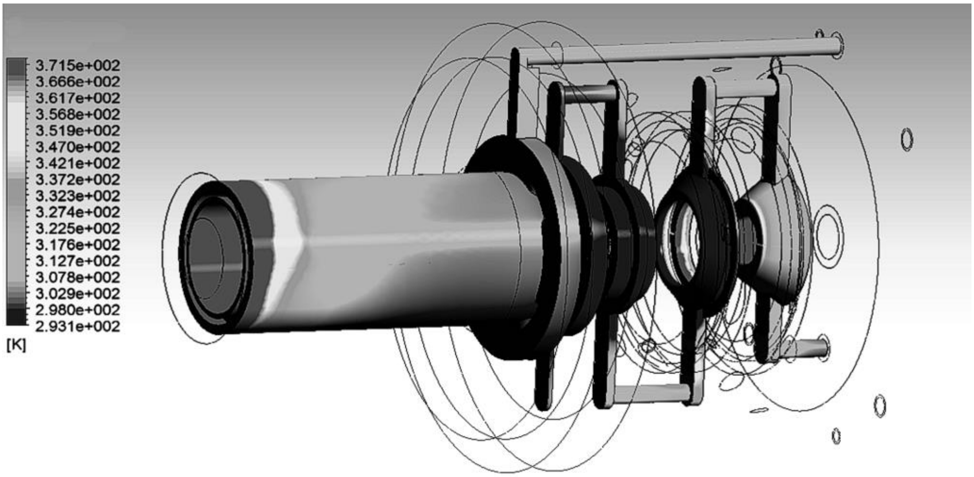

Figure 8 – Water temperature distribution[8.9]

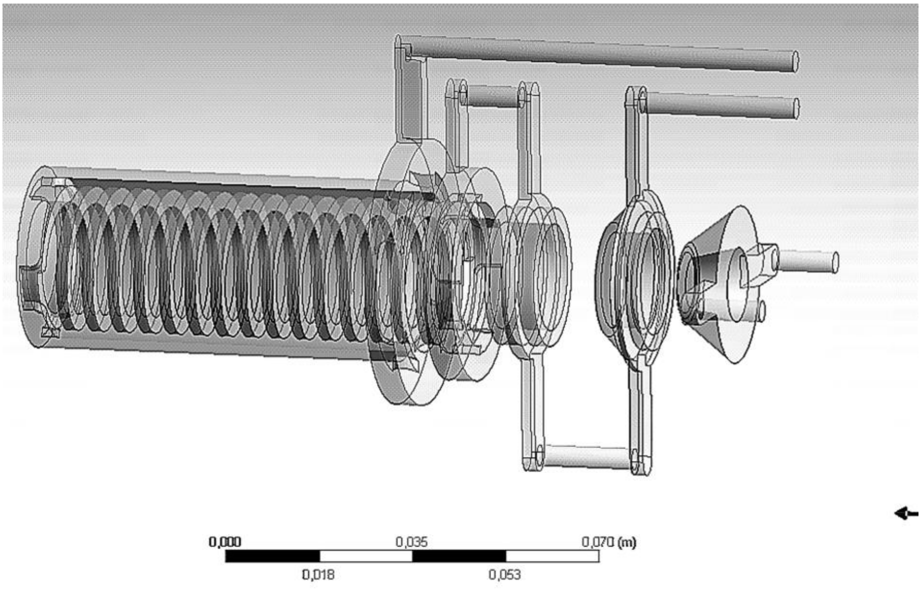

Figure 9 – Modified area of the cooling path[8.9]

As a result of calculations for the most unfavorable case, when the wall of the plasmatron is heated by an electric arc to a temperature close to the melting point, it was determined rational water consumption, which was for the anode part – 1.0 kg/s, for the cathode part – 0.7 kg/s. At the same time, the boiling zones are practically absent, as a whole the cooling system is rather successful, temperature of walls is distributed evenly (Fig. 10).

As a result of calculations, it was made the set of documentation on a plasmatron prototype (Fig. 11) for the problems of gasification of raw materials and work in the conditions of excess pressure.

The results of numerical simulations showed that under conditions of excess pressure at the outlet of the plasmatron significantly increases the partial pressure of oxygen-containing gases in the cathode space, which can adversely affect the emission characteristics of the cathode material. On the basis thereof, the need to take into account the value of excess pressure at the nozzle section, when designing gas-discharge channels of electric arc plasma generators using the method of automated design, is justified.

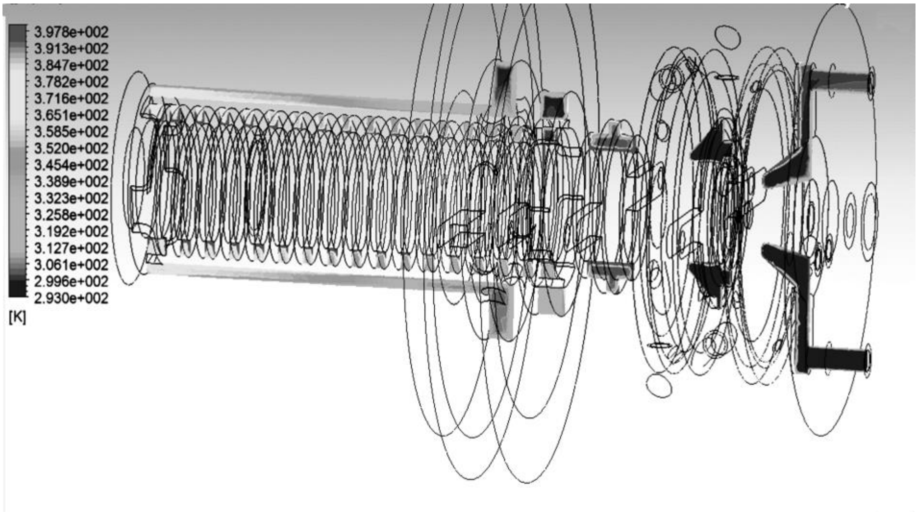

Figure 10 - Water temperature distribution[8.9]

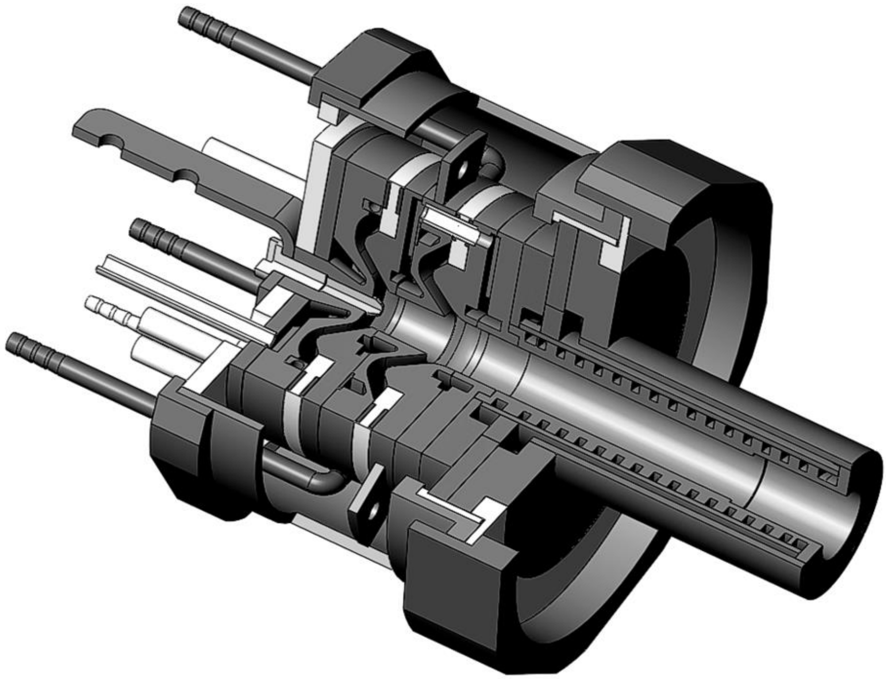

Figure 11 - Three-dimensional model of the developed plasmatron[4.10]

Conclusions

1. It was improved the designing method of gas discharge channels of plasmatrons in the integrated CAD/CAE-systems using the mathematical models proposed by the authors in [4, 8] using the criterion of taking into account the usage conditions of plasma equipment, namely the hydraulic resistance of the gas path of the system as a whole considering the excess pressure at the outlet of the plasmatron. In the environment of CAD/CAE-system, it was developed mathematical models to calculate parameters of the plasmatron cooling system.
2. Using the developed technique, it was designed the prototype of a plasmatron intended to be used as a part of installation for gasification of raw materials and the set of documentation as well. In the course of numerous experiments, it was shown that in the modified plasmatron the absence of reverse currents and the atmosphere required for the constant operation of the thermoemitter are ensured [8-10].

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