Ministry of Science and Higher Education of the Russian Federation
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Microwave plasmatron based on a waveguide bridge

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Abstract. The paper deals with the development of a new microwave plasma torch design, which has several advantages over the known ones.
A “classical” microwave plasmatron is a rectangular waveguide on an $\mathbf{H_{10}}$ wave and a dielectric discharge tube passing through the middle of its wide wall.
To connect such a plasma torch to a microwave generator, we use a simple three-decibel waveguide bridge instead of a complex and expensive circulator.
At the same time, the high efficiency of the microwave power input into the plasma, the conditions for initiating and maintaining the discharge, and also the protection of the magnetron from the reflected wave in the absence of discharge are maintained.

1. Introduction

In recent decades, because of the development of microwave technologies and the mass production of cheap magnetron generators, many scientific works have appeared on the creation and use of atmospheric-pressure microwave plasmatrons. Mostly in use the frequency 2.45 GHz, with a power of up to several kW. [1, 2] The plasma jet temperature, in this case, can reach several thousand Kelvin degrees [3].

Such plasmatrons has wide application in modern technologies: plasma technologies for gas purification from toxic and infectious emissions; solid waste incineration; modification of the working surfaces of parts made of steels, alloys and semiconductor materials before nitriding, cleaning or etching operations, and many others [4].

A classical microwave plasmatron consists of a rectangular waveguide on an $\mathbf{H_{10}}$ wave mode and a dielectric discharge tube passing through the middle of its wide wall. Device can be connected to a microwave generator using both, console or through-pass scheme.

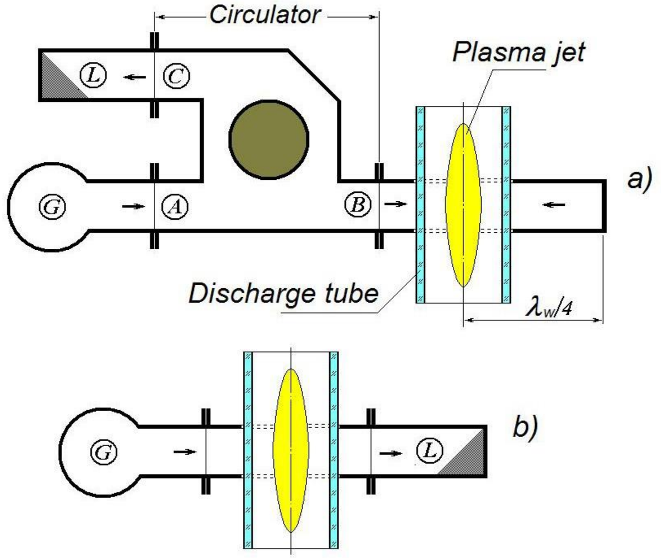

Figure 1. *Connection of the microwave generator G to the plasma torch according by the a) – console, and b) – through-pass schemes.*

In the case of a console-connection, the waveguide after the discharge tube must end a movable or fixed short-circuit piston. However, it is necessary to effectively protect the magnetron from reflected waves in the plasma absence case.

In **Figure 1a**, the microwave energy from the magnetron generator G feeds the plasma jet in the discharge tube of the plasma torch through the shoulders A and B of the circulator. The reflected and unused part of the energy returned to the shoulder C of the circulator and absorbed in the matched load L. In **Figure 1b**, the waveguide after the discharge tube is loaded on a matched load L and, thus, the magnetron G is protected without using a circulator. However, the conditions for initiating and maintaining the discharge are getting worse. The part of microwave energy, which not absorbed by the plasma, losses in the load.

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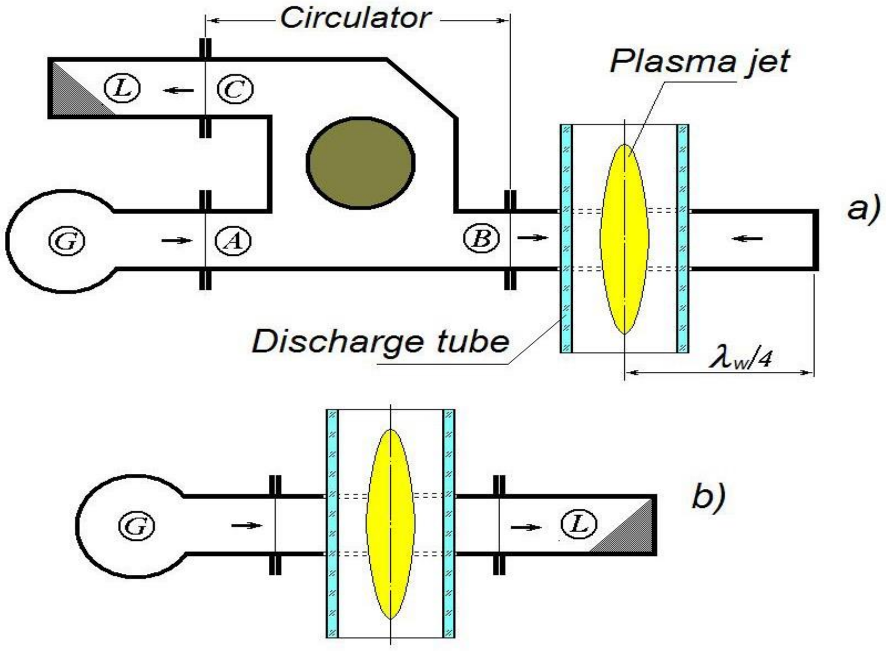

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2. Technical description

The main idea is to replace the circulator used in the console circuit (Figure 1a) with a three-decibel waveguide bridge. Such a bridge divides the power entering its input arm strictly in half between its two output arms. Its unique property is that if both output arms of such a bridge are loaded on any arbitrary but identical loads, then all the power reflected from them will go to the fourth, untied shoulder of the bridge. By connecting the matched load to the untied shoulder, we will save the microwave generator from troubles, even in the case of very significant reflections.

Figure 2 diagram of the described above device. The power, coming from the microwave generator G to the input arm A of the waveguide bridge, is divided in half at the output arms B and D. Both of these output shoulders of the bridge are loaded on identical, short-circuited segments of the waveguides.

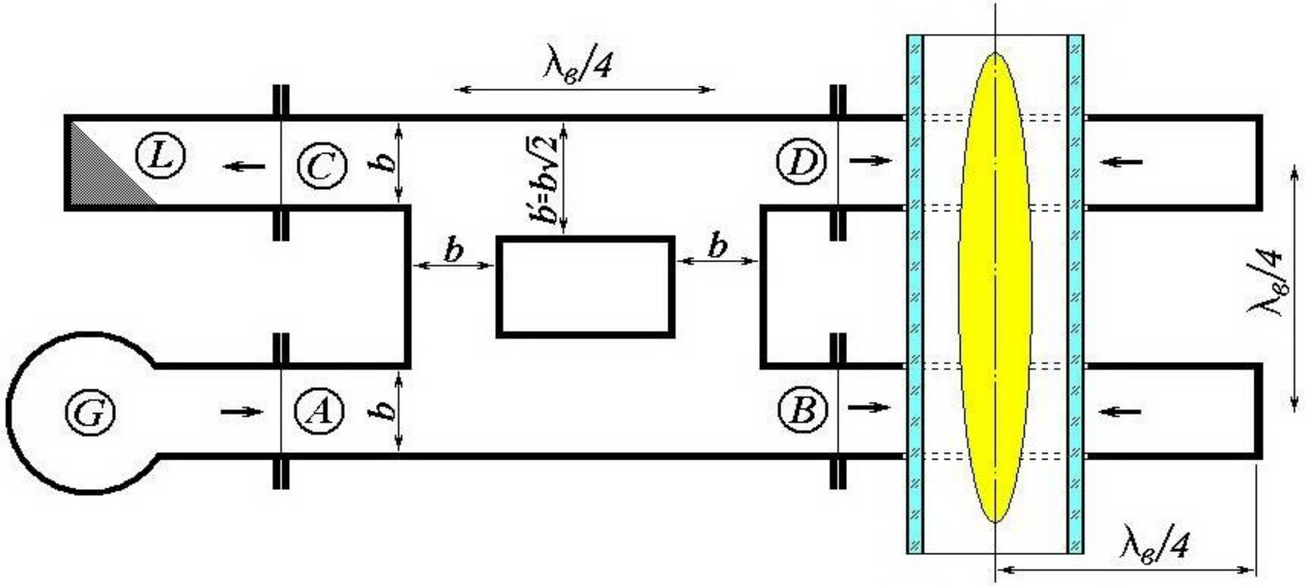

Figure 2. *Diagram representing the main idea of this publication (explanations are in the text).*

On a quarter wavelength from the short-circuited ends of these waveguides, in the middle of their wide walls and perpendicular to them, is a discharge tube. Under the assumption that the output shoulders of the bridge will be loaded symmetrically, reflected from the short-circuited ends, in the absence of discharge (or not absorbed in the plasma jet), the microwave power is returned to the untied shoulder C of the bridge and absorbed by the matched load L.

2.1. Construction design and optimization of the calculation model

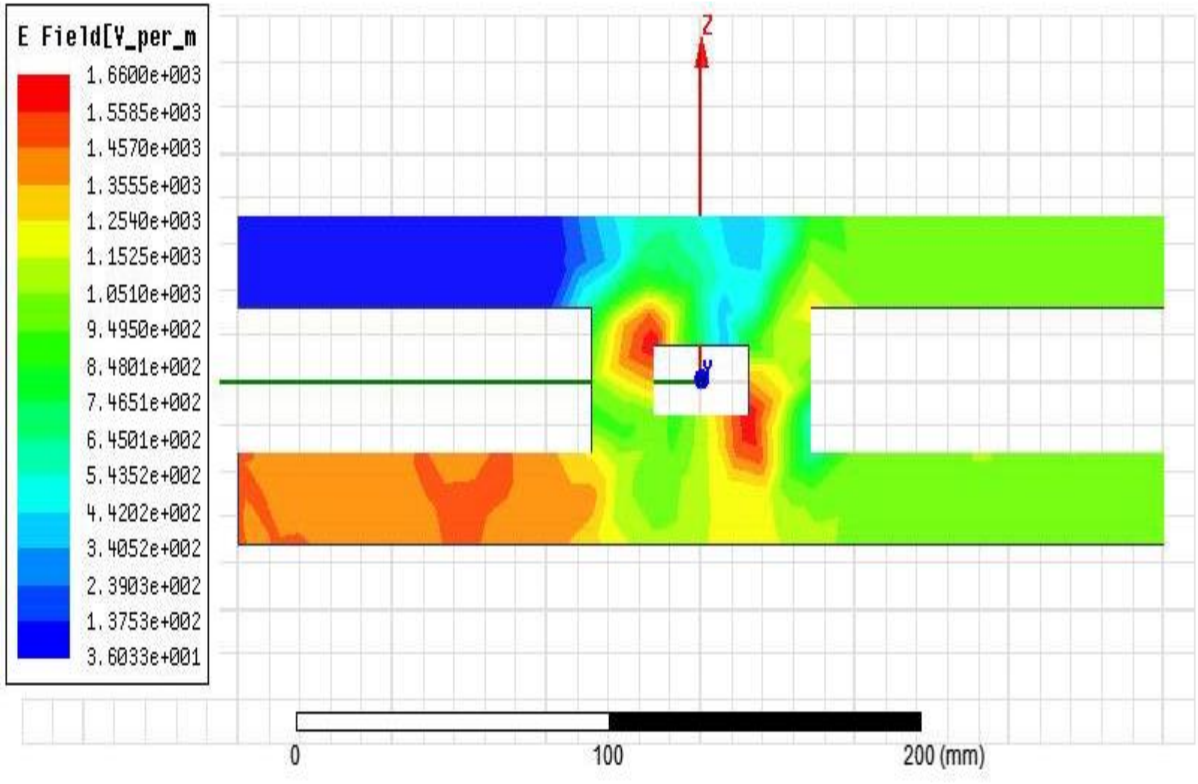

Figure 3. *Section of an optimized model of the electrodynamics structure of a three-decibel waveguide bridge.*

The basis of such a device, we chose is a three-decibel waveguide bridge with communication over a wide wall. For geometric parameters and their subsequent optimization calculation were using the HFSS, electrodynamics modeling of microwave structures program.

A longitudinal section in plane E of the calculated model of the electromagnetic structure is shown in Figure 3. The arrangement of the main elements of the circuit corresponds to those shown in **Figure 2**. The difference is that the output shoulders of the bridge are conditionally loaded to the matched loads. This was necessary for the optimization of the geometric dimensions of the bridge. The width of all waveguides (located perpendicular to the plane of the figure) is selected 90 mm, equal to the width of the waveguides of the standard WR-340. The height of the “external” waveguides (size “b” in **Figure 2**) was chosen equal to 20 mm according to the optimization results and according to the conditions of permissible power for electric strength. The section in conventional colors shows the magnitude of the complex amplitude of the electric component of the electromagnetic field. It can be seen that in all the “external” waveguides the traveling wave mode was established, including in the supply waveguide (corresponding to the input arm A in **Figure 2**), the calculated value of the VSWR at a frequency of 2.45 GHz does not exceed 1.05.

2.1. Construction design and optimization of the calculation model

In **Figure 4**, the same model as in **Figure 3**, but the output shoulders of the bridge loaded on identical short-circuited segments of the waveguides. According to the image, the calculated electric field strength in the antinodes of the standing wave exceeds 10^5 V/m with a generator power of 2.5 kW. The estimated value of the VSWR at the entrance of the bridge is about 1.1 - 1.15. This is quite enough for the safe operation of the magnetron generator.

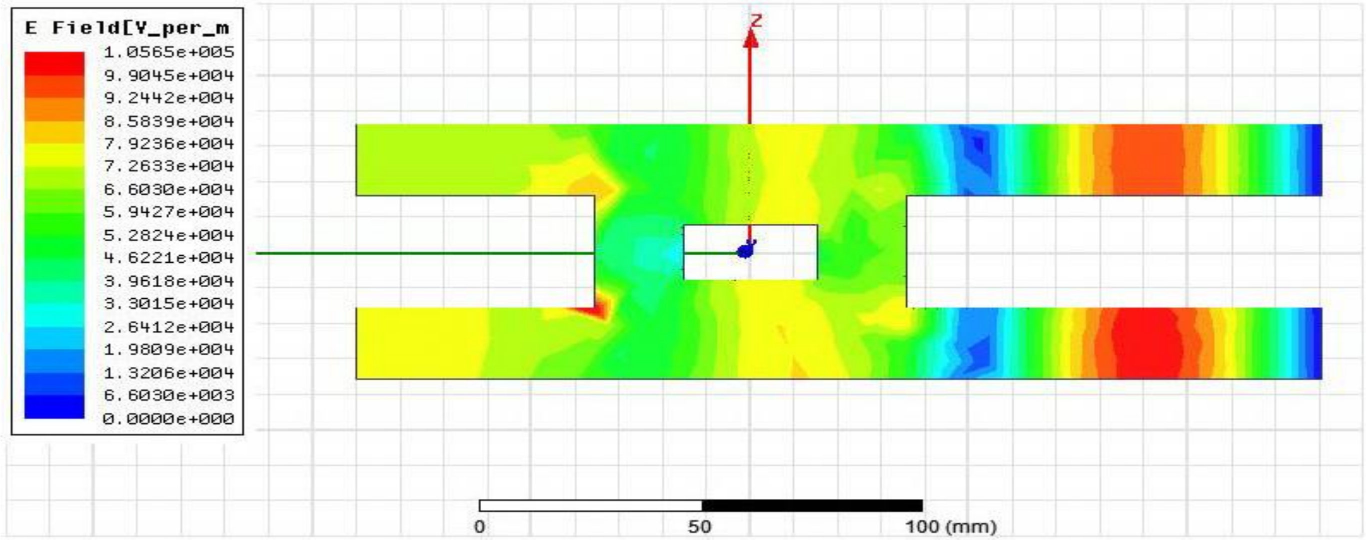

Figure 4. *Electrodynamics model. Section of the three-decibel waveguide bridge with short-circuited waveguides on the output*

2.2. Design, manufacture, and testing of the demonstrator model

As a result of the calculation of the geometric parameters of the waveguide bridge, an experimental model of a microwave plasmatron was developed (Figure 5).

In the shoulders of the bridge, there are smooth matching transitions to the standard section of waveguides (90*45 mm). Flange offset is required for device assembly conditions.

The main problem that bothered us during the entire time of solving this task was the following. Will the necessary phase and amplitude ratios in the output arms of the bridge be preserved in the case of a strong electromagnetic connection between them through a common plasma jet?

The theoretical answer to this question seemed to us very difficult, only a direct experiment could solve it. And this day has come!

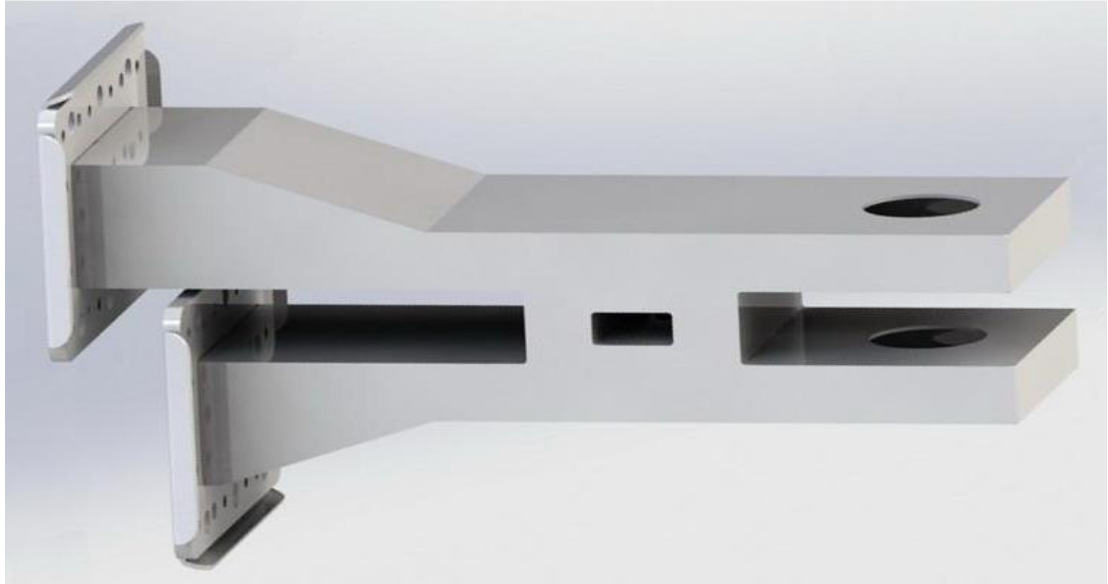

Figure 5. *Computer design of an experimental model of a plasma torch*

2.2. Design, manufacture, and testing of the demonstrator model

Figure 6 shows the operating moment of fire tests of a microwave plasma torch based on a three-decibel waveguide bridge. Working gas is air, flow rate 20 l/min, microwave generator power 2 kW. The supply waveguide is connected from below, and a water load is attached to the untied bridge shoulder from above. To the holes in the waveguides through which the discharge tube passes, segments of round below-cutoff waveguides are welded. This is done to suppress microwave radiation in the absence of a plasma discharge.

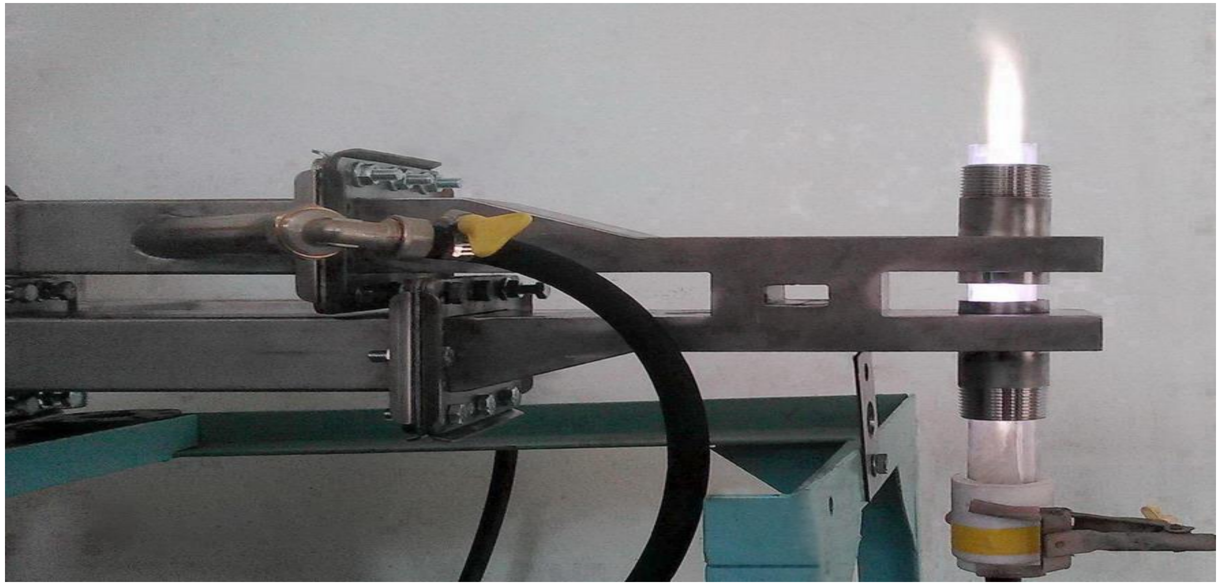

Figure 6. *Microwave plasmatron based on a three-decibel waveguide bridge*

2.3. Our plans to continue working

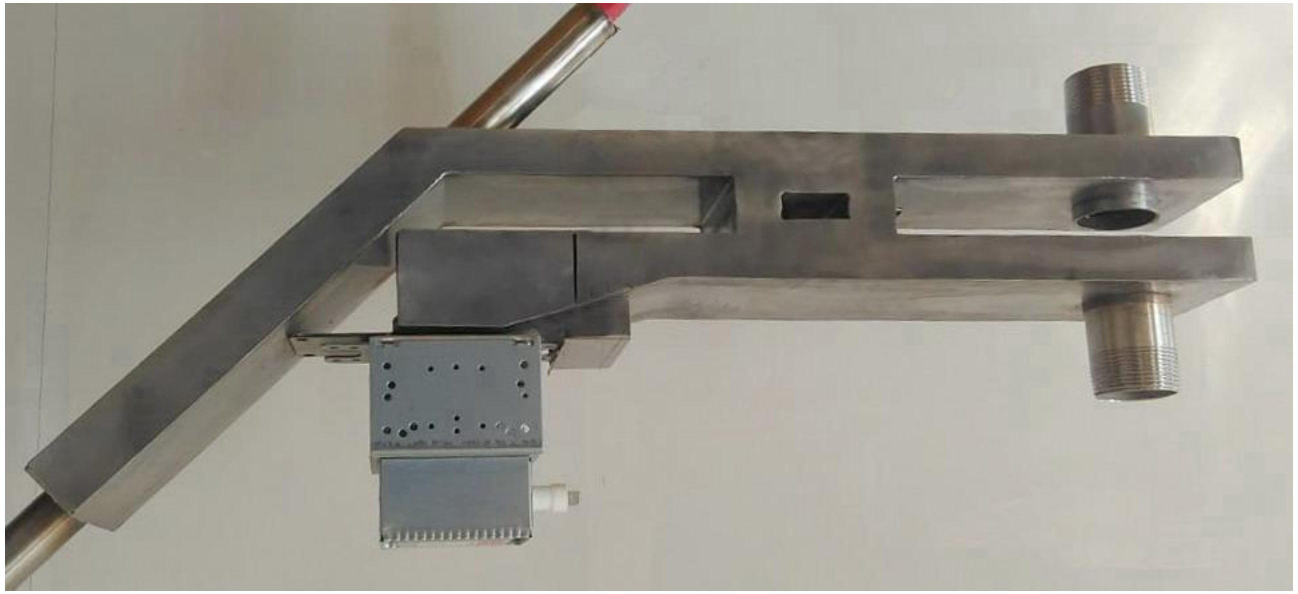

Figure 7. All-welded waveguide path for a microwave plasmatron based on a three-decibel bridge.

The results achieved in this area allowed us developing a non-separable, all-welded waveguide path for a microwave plasma torch based on a three-decibel waveguide bridge. This is simplified, low-cost and reduces the dimensions of such a plasma source as a whole.

Figure 7 shows a prototype of an all-welded microwave plasma torch based on a three-decibel bridge. The location and purpose of the shoulders of the bridge are similar to those presented above.

3. Conclusions

Calculations and optimization of the electromagnetic system parameters of the proposed microwave plasma torch model using the capabilities of the Finite Element Method of the HFSS program were implemented into the design and manufactured experimental model.

The tests brilliantly confirmed the possibility of creating an inexpensive microwave plasmatron based on a three-decibel waveguide bridge without the need for a complex and expensive circulator to protect the magnetron breakdown from possible reflections of microwave energy.

The solution of the problem found by the authors is recognized as an invention, and the copyright is protected by a patent of the Russian Federation [5].

Thus, the presented device can be used both independently and as part of a universal low-budget hardware microwave complex for producing non-equilibrium low-temperature plasma [6].

This work was supported by the Russian Foundation for Basic Research (project No. 20-08-00894).

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Thanks for your attention