Effect of Dust Grains on the Electrical Properties of Torch Discharge

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Abstract. Measurements of capacitance and active resistance of the high frequency torch discharge burning in the air while it had been polluted by the dust of dielectric and conducting materials were made. Increasing of active resistance of the torch discharge while it had been polluted by the dust of nickel was determined. The coefficient of conversion of electromagnetic energy into thermal energy was calculated. It has been shown that the maximum coefficient of conversion of the electromagnetic energy into thermal energy can be observed when the degree of dust pollution is $6 \cdot 10^{-6}$.

INTRODUCTION

The high frequency torch discharge has been used recently as a source of plasma in various technological processes [1, 2]. To increase the efficiency of the processing of raw materials, it is expedient to introduce it directly into the plasma of the discharge. The introduction of a processed material into the discharge plasma significantly changes its characteristics, primarily due to the appearance of new chemical compounds. In the work [3] it was considered the effect of additives associated with the plasma-chemical process and the chemical compounds corresponding to the additives on the electrodynamic characteristics of the discharge. However, the question of changing the conversion efficiency of the energy of transverse magnetic wave [4], which maintains the burning of the discharge during its dusting, into the thermal energy remained unresolved.

In the article the determination of impedance of the torch discharge dusted by conducting and non-conducting materials has been made. The assessment of the discharge parameters has been conducted for various degrees of dust content. Based on the results an estimation of the value of the energy conversion coefficient of electromagnetic wave into thermal energy was conducted.

RESEARCH METHODS

The high frequency torch discharge was excited in the quartz cylindrical chamber with the diameter of 28 mm and frequency equaled to 37.5 MHz. The air was used as a plasma forming gas. The air flow was equal to 1.2 m^3/h. The dust materials that were polluting the plasma were placed into the discharge through the central hole of the electrode with the help of a pneumatic feeder. The power of discharge was varied from 0.5 to 3.0 kW.

The determination of impedance of torch discharge was conducted by resonance method [5, 6]. The measurement scheme was the same as that used in the work [7]. Its principle scheme is given in the Fig. 1.

The parallel oscillatory circuit was coupled with the output of the high frequency generator through the split capacitors. Alteration of characteristics of the oscillatory circuit was made by the change of capacitance of variable capacitor. The point of resonance was determined according to the maximal value of current going through the electrode of torch discharge. The current was measured by Rogowski loop. The value of the capacitance C_L for the resonance of the circuit was determined without burning of the discharge and with burning of it. Gained value of the capacitance alteration was identical with the capacitance of discharge C_d.

Functionally additional oscillatory circuit was represented as separate metal box with inductance L and variable vacuum capacitor C_L in it. Input capacitance C_1 and C_2 were made in the form of air-dielectric capacitor

V International Conference for Young Scientists, Post-Graduate Students and Students
AIP Conf. Proc. 2101, 020018-1–020018-4; https://doi.org/10.1063/1.5099610
Published by AIP Publishing. 978-0-7354-1831-8/$30.00

equaled to 1.5 and 4 pF respectively. Measurements of high frequency voltage were made by multimeter with capacitor splitter. Measurements of the high frequency current's volume were made by Rogowski loop.

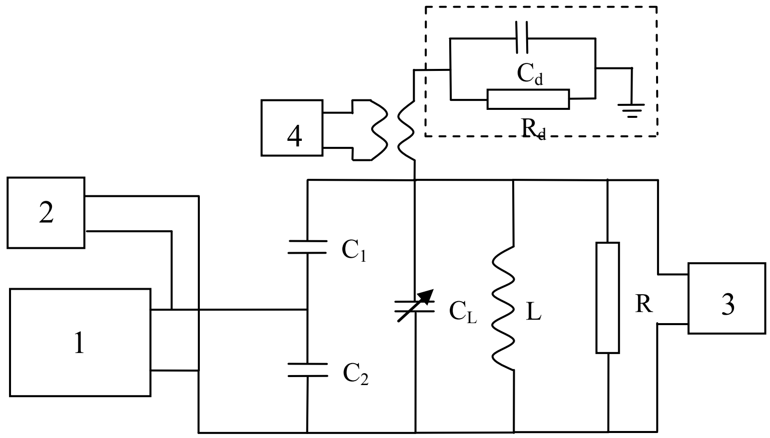

FIGURE 1. Electrical scheme of measure circuit: 1 – high frequency generator; 2, 3 – multimeter; 4 – Rogowski loop

Equivalent electrical scheme of torch discharge can be represented in the form of consistently connected capacitance and active resistance. This electrical scheme is called [8] Neumann scheme. For comfortable calculations also modified Neumann chain is used. It's given in the Fig. 1.

Resistance of discharge was determined according to output voltage of oscillatory circuit to input voltage. For the scheme given on the Fig.1 the following equation is right:

$$\frac{U_2}{U_1} = 1 - \frac{1}{1 - \dfrac{\omega^2 C_2 RL}{\mathrm{j}\omega L + R(C_L L\omega^2 - 1)}},$$

where: j – is the imaginary unit; ω – curcular frequency of the electromagnetic field; U_2 – output volatge; U_1 – input voltage of the electrical field.

Cosine calculation of the phase shift between current going in the discharge and voltage across high voltage electrodes was made basing on the measured impedance of the discharge. Calculation of the phase shift was made according to the following formula:

$$\varphi = \operatorname{arctg}\frac{1}{\omega CR},$$

where: C, R – respectively capacitance and active resistance of torch discharge. Capacitance and active resistance of torch discharge were determined in accordance with equivalent Neumann scheme [8].

RESULTS AND DISCUSSION

Measurement results of impedance of torch discharge burning in the air are given on the Fig. 2. Dotted curves refer to the case of discharge without dusted pollution. Solid curves are given for the case of discharge polluted by the nickel. The degree of discharge dusted pollution which was determined as ratio of the volume of evaporant to the general volume of discharged chamber was equaled to $4 \cdot 10^{-6}$.

As it is seen on Fig. 2 with the increase of the length of the channel and accordingly of the discharge power, the discharge capacitance increases and the active resistance of the discharge dicreases. It should be pointed out that cosine of the phase shift between current and voltage equals to about 0.7 -0.8. This result coincides with the results of the work [9], according to which the value of active current component in the discharge is more than the value of reactive component of current.

As it is shown on the Fig. 2, capacitance of dusted nickel discharge differs slightly from the capacitance of torch discharge burning without condensed phase. At the same time discharge resistance while nickel dusted pollution increases on 10-15%.

The increase in the resistance of the discharge plasma is apparently due to the capture of electrons by nickel grains. The decrease in plasma electrical conductivity in turn increases the attenuation degree of the electromagnetic wave supporting the discharge burning. This changes the efficiency of the process of converting electromagnetic energy into heat.

For torch discharge dusted with nickel, there was made a calculation of cosine of the phase shift between current and voltage on the high voltage electrode. It should be noted that this value characterizes [10] the degree of processing the electromagnetic energy putting to the discharge into the thermal energy.

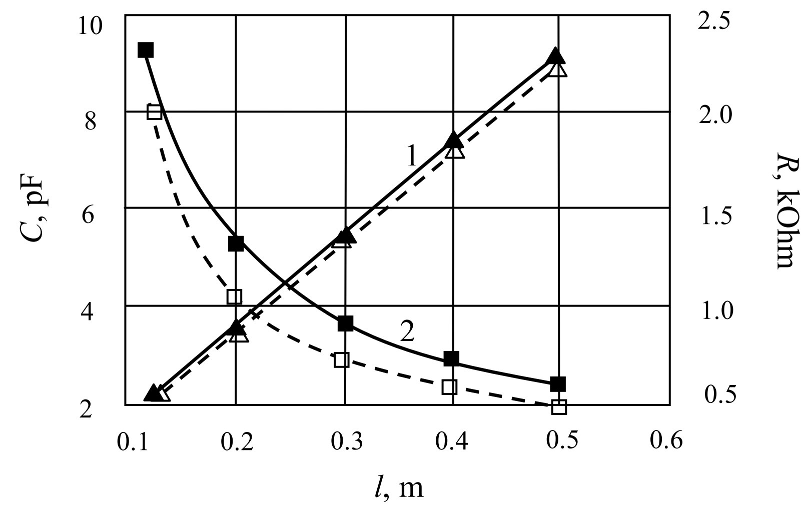

FIGURE 2. Dependence of active resistance and volume of torch discharge from the length of it channel: 1 – capacitance; 2 – active resistance

The results of the calculation made for the torch discharge with the degree of dusting pollution equaled to $4 \cdot 10^{-6}$, and are given on the Fig. 3. On this figure calculation data of cosine of phase shift for torch discharge without dusted pollution is given. Cosine of phase shift between current and voltage of torch discharge increases according to its increase of power. This conclusion is right for both burning freely and dusted discharge.

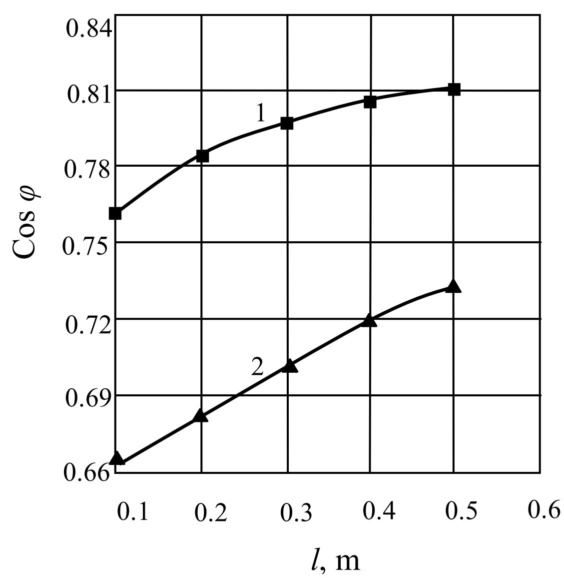

FIGURE 3. Dependence of cosine of phase shift between current and voltage of torch resistance from the length of its channel: 1 – discharge dusted with the nickel; 2 – discharge without dusted pollution

Nickel-dust-laden torch discharge can be used to apply plasma powder coatings. When feeding nickel powder directly into the discharge zone, it heats up better, which improves the characteristics of the resulting coating. When using a dusty torch discharge for applying coating, there arises the problem of optimizing its burning regimes.

The measurement of cosine of the phase shift between current and voltage of torch discharge with power 1 kW and various degrees of its dusted pollution was made to full fill this purpose. On the Fig. 4 the results of measurements are presented. From the Fig. 4 it follows that the maximal coefficient of processing the electromagnetic energy into thermal one for torch discharge with the voltage 1 kW burning with the atmospheric pressure in the air it is observed with the degree of its dusted pollution equaled to $6 \cdot 10^{-6}$.

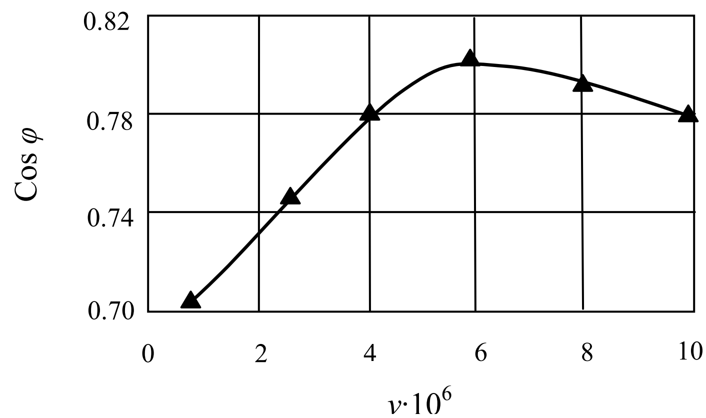

FIGURE 4. Dependence of cosine of phase shift between current and voltage of torch resistance from the degree of its dusted pollution with the nickel

CONCLUSIONS

As a result of the measurements it was found that active resistance of torch discharge while it dusted by conducting material increases. The change of the value of discharge capacitance under these conditions turned out to be slight. With increase of the active resistance of torch discharge the increase of coefficient of conversion of electromagnetic energy is observed. This increase is 5-7%. For the discharge with the power of 1 kW it is found that with the degree of its dusted pollution of $6 \cdot 10^{-6}$ the conversion coefficient of electromagnetic energy supplied to the discharge into thermal energy, is maximum. In connection with this, the above degree of the dusted pollution of the discharge can be recommended as an optimum for carrying out plasma processing of materials.

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