Induction plasma heating installation for heat treatment of powder materials

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Abstract. In this article the work results on the creation at the Department of Electrotechnology and Converter Engineering in ETU "LETI" of a high-frequency induction plasma research installation designed for high-temperature plasma treatment of powder oxide and other materials in order to obtain melted spheres and different dispersion and structure powders, as well as high-temperature plasma surface treatment to give them special properties are presented. The device has already started operation and is currently producing various oxide materials. The operation characteristics of the HFI-plasma torch and the processed materials during powders spheroidization of quartz sand, electro corundum, phosphate glass and melted stabilized zirconium dioxide are obtained.

1. Introduction
Recently, using low-temperature plasma produced a large number of unique processes. These include: welding and cutting of refractory metals and other materials; application of protective, ceramic thermal barrier and electrical insulation coatings on various materials; preparation of nano dispersed metal powders [1 – 5] and their compounds for metallurgy [2, 5]; spheroidization of powders of refractory substances; thermal neutralization of highly toxic and radioactive organic and inorganic waste; synthesis of chemical compounds; pumping a powerful gas lasers; plasma excavation of sturdy rocks; melting and refining of metals; the use of plasma in the engines of space vehicles, etc. All of them require generating and sustaining of plasma, which is used to power up plasma torches [6 – 8].

One of the promising types of plasmatrons is an induction plasmatron, which has a number of advantages over other plasma generators, namely: high plasma temperature (8000 - 11000) °K, which allows to process and melt the most refractory materials; no pollution introduced into the plasma flow; the ability to obtain plasma in the atmosphere of any gases, including in an oxidizing atmosphere (oxygen, chlorine); longer service life compared with arc plasmatrons associated with the absence of wear parts; the ability to create installations with a capacity of up to several megawatts [9, 10].

All applications of high frequency induction (HFI) of the plasmatron can be divided into three groups: the first group – the use of plasma as a source of thermal effects (crystal growth, particle spheroidization, plasma spraying, etc.); the second group – the use of plasma for carrying out plasma-chemical reactions (production of optical waveguides, the synthesis of ultrafine ceramic and metal powders, the synthesis of high-purity quartz glass and nano materials, etc.); the third group – the installations of the spectral analysis of materials [9].

The purpose of this work is to create and launch the induction plasma installation with measurement systems for the study of heat treatment of oxide materials, research and laboratory work on the study course "Electrotechnology installations and systems".
2. The launch of HFI-plasma torch
For the successful implementation of the task, the following main stages of work were performed:
supply of electric energy; creation of a process unit; installation of an inductor and a discharge
chamber; organization of water cooling of the installation; installation of a plasma gas supply system;
installation of a calorimetry system; start of installation and testing of measurement systems.

The installation has the following main parameters: power supply – high-frequency tube generator
with oscillatory power of 60 kW and a current frequency of 1.76 MHz. A set of the induction plasma
torches with a cylindrical water-cooled discharge chamber with an internal diameter of 50 mm and a
length of 300 mm. The chamber is separated from the inductor by a quartz pipe. The velocity of
plasma flow is determined by the flow rate and the nature of the plasma gas. A wide range of plasma-
forming gases were used. The installation operates at atmospheric gas pressure.

Plasma ignition is carried out by introducing a grounded graphite electrode into the discharge
chamber, using argon as the primary plasma-forming gas with the lowest ionization potential. Then,
when the plasma is ignited, there is a smooth transition from argon to another gas, for example,
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Figure 3. The time variation of the powers allocated in the plasma torch elements.

The maximum operating mode of the generator during the tests is as follows: voltage at the anode of the generator tube $U_a = 9.5 \text{kV}$; anode current of the generator tube $I_a = 7.5 \text{ A}$; grid current of the generator tube $I_g = 1.4 \text{ A}$.

The achieved mode of operation in the tests indicates the optimal setup of the generator, the good operation of the induction plasma torch and the measurement system.

3. Study of oxide materials powders spheroidization
The study of powders spheroidization for different materials with different fractions was carried out. Powders of oxide materials with different melting points were passed through the flame stream: cubic zirconium, stabilized with yttrium oxide, melted electrocorundum ($\text{Al}_2\text{O}_3$), phosphate glass and quartz sand. All these materials had a size fraction from 250 to 500 $\mu\text{m}$. Powders of fraction less than 250 $\mu\text{m}$ were treated separately.

For optimal processing of powders, the melting temperature of the feed material was taken into account. Thus, for the treatment of zirconium oxide, which has a maximum melting point of all materials, the generator mode was maximum.

As the first material for powders spheroidization in the plasma flow, the gross fraction of quartz sand was used. The sand was passed through the plasma working in the air. In Figure 4 the type of material before and after plasma treatment is shown.

Figure 4. Quartz sand before and after plasma treatment.
The maximum diameter of the quartz sand spheres was 500 µm. Almost all particles turned out hollow, indicating excessive outgassing during cooling. When passing quartz sand through the plasma clot, the outgoing plasma jet was colored orange, which indicates the evaporation of fusible components (impurities) of quartz sand. As a result of plasma treatment, transparent spheres of quartz sand with very good flowability of the material without caking are obtained.

The second stage was treated with powder of zirconium oxide stabilized with yttrium, with a size less than 500 µm. Photos of the material before and after plasma treatment are shown in Figure 5. The size of the melted particles reached 400 µm. In some cases, gas bubbles were observed inside the particles, as well as incomplete melting and spheroidization. The color of the resulting material was different.

Then, the powder of fused aluminum oxide (corundum) was processed in the plasma. Photos of the material before and after processing are shown in Figure 6. The size of the melted particles reached 600 µm.

![Figure 5. Zirconium dioxide before and after plasma treatment.](image)

![Figure 6. Corundum (melted aluminium) before and after plasma treatment.](image)

After that, in the plasma the powder from pulverized synthesized phosphate glass was treated. The diameter of the particles did not exceed 400 µm. Photos of the material before and after processing are shown in Figure 7. After plasma treatment, the particles of phosphate glass powder turned into hollow spheres. In addition, melted particles much greater than the maximum original size, indicating that the adhesion of the molten particles of glass.
Figure 7. Phosphate glass before and after plasma treatment.

Much of the phosphate glass powder, fed into the plasma, has evaporated. This indicates the necessary to reduce the plasma temperature, or reduce the processing time.

4. Obtained results
As a result of the tests, the best modes of the plasmatron operation for powders spheroidization of quartz sand, corundum, phosphate glass and stabilized zirconium oxide were selected. The required power supply and flow rate of plasma-forming gas in the processing of the each presented materials are determined.

Figure 8 shows the experimental dependence of the feed particles size materials under study on their melting temperature. For phosphate glass the melting temperature is indicated.

Figure 8. Dependence of the spheroidized particles size on the melting temperature of materials. For phosphate glass, the melting temperature is indicated.

The curve delimits the field of spheroidized and the not enough melted particles of the investigated materials. The obtained dependence refers to the conditions of material passing through the entire plasma flow. To increase the yield of suitable particles of melted materials and reduce their
evaporation, it is necessary to introduce the starting materials (powders, solutions, etc.) into the plasma flow at the plasmatron outlet, where the temperature and processing time is much lower.

The high-melting substances with a melting point of over 2500 °C, the possibility of installation is currently limited processing of spheroidized materials particles up to 100 µm. To increase their size, it is necessary to significantly increase the residence time of the particles in the plasma, for example, using a tangential twist of the plasma flow.

It is noticed that when passing of different materials powders through the plasma torch, the plasma jet at the exit changed it is color the more than material was supplied to the plasma, and the smaller the powder fraction was used. This is due to the evaporation of various materials. For example, when processing quartz sand, the white color of the plasma became orange, and, when processing the smallest fraction of aluminum oxide, the plasma color was bright blue.

5. Conclusion
At the Department of Electrotechnology and Converter Engineering in the laboratory of induction melting in a cold crucible [10] the new installation of plasma heating and melting of substances using the power supply of 100 kVA with a current frequency of 1.76 MHz was created and successfully launched. The efficiency of the installation and measurement systems was described.

As a result of the tests, the best modes of the plasma torch operation associated with the required power supply and the plasma-forming gas flow rate for a particular fraction of various oxide materials and glass were selected.

As a result of the research, the experimental dependence of the particle diameter above which spheroidized granules are obtained on the melting temperature of the material is obtained. The obtained dependence allows choosing the particle sizes of materials for their successful spheroidization. In further research, as the process is optimized and other materials are processed, the curve will be adjusted.

The installation used for carrying out of scientific researches and laboratory works. In the future, it is planned to equip the installation with new measurement systems and technological systems, such as advanced dosing and material collection systems, as well as experimental studies on plasma spraying, spheroidization of the other materials powders, etc.

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