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AN EXPERIMENTAL STUDY OF INFLUENCE OF DEGREE OF SWIRLING OF A PLASMA AIR JET AND INTRODUCTION OF NATURAL GAS INTO IT ON TEMPERATURE AND VELOCITY FIELDS

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The results of the measurement of temperature and velocity fields of swirled plasma jets are presented. An improved method is proposed for measuring the temperature of a plasma.

The swirling of gas streams finds application for the stabilization of arc burning in plasmotrons [1], for improvement of the process of mixing gas jets [2], and for increasing the coefficient of heat transfer to particles in the spraying of a number of materials [3]. In contrast to straight-flowing plasma jets, swirled jets possess a higher mixing intensity, a large expansion angle of the jet, and an increased ejecting capacity, which is particularly important in the creation of plasma-chemical reactors and of devices for plasma spraying.

The processes of particle heating in the plasma jet of an oblique-action plasmotron can be investigated only when the detailed pattern of the gas-flow dynamics and the three-dimensional pattern of the temperature field are known [4]. It has now been established that the variation in the velocity profiles in a plasma jet has a complex character depending on the degree of swirling, the distance to the nozzle cut of the plasmotron, and the gas flow rate [5, 6]. Unfortunately, the existing methods of calculating the propagation of swirled turbulent jets do not give satisfactory results for the main section of a plasma jet. Therefore, the dynamic structure of swirled plasma streams can now be established on the basis of experimental data obtained under one or another concrete conditions.

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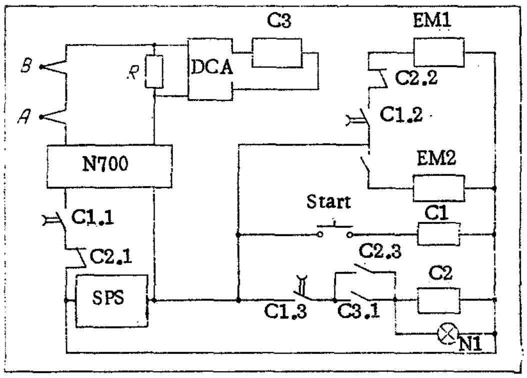

Fig. 1. Block diagram of the installation for temperature measurement: SPS) stable power supply.

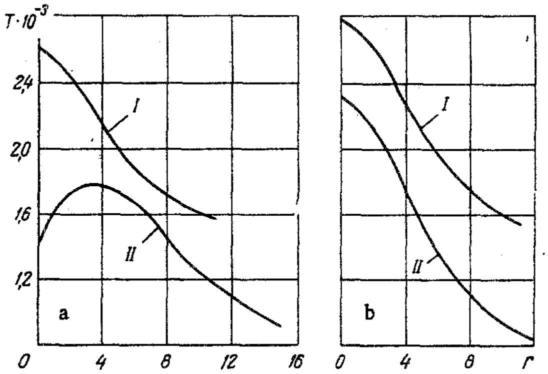

Fig. 2. Radial temperature distributions in a plasma air jet at a distance of 30 mm from the nozzle cut of the plasmotron: a, b) air flow rates $G_{air} = 5$ and 2.8 g/sec, respectively; I) air + 5% CH_4; II) air; $T \cdot 10^{-3}$, °K; r, mm.

Moreover, the question of the interrelationship between the gas-flow fields and the temperature fields has not been clarified up to now. The question of the influence of combustible-gas admixtures (such as natural gas) on the character of the flow in a strongly swirled jet in the presence of axial return flow is almost entirely uninvestigated. The difficulty of a theoretical investigation is aggravated by the fact that with the introduction of combustible gas the process is accompanied by a change in volume.

The interrelationship between the three-dimensional temperature distribution and the dynamics of air flow in weakly and strongly swirled jets with and without natural-gas admixtures is investigated experimentally in the present report. By the term weakly swirled jet we understand a jet such that all the maxima in the radial distribution of the axial velocities lie at the jet axis, while a strongly swirled jet is one in which there is a region of return flow of the gas.

The measurements were made in a plasma air jet discharging from a two-chamber plasmotron with vortical stabilization of the arc and with a power of 30 kW. The natural-gas admixture (98% CH_4) was introduced into the jet radially at a distance of 0.5d from the nozzle cut through an opening in the anode (d is the inner diameter of the anode, equal to 26 mm). The air flow rate was varied from 1.2 to 5 g/sec. The air was supplied to the chamber tangentially through a gas-swirling disk.

To measure the temperature of the jet we chose the method of a dynamic thermocouple, which has a high spatial resolution and simplicity of the measurements. The thermocouple material was Pt–Pt + 10% Rh. The temperature was calculated from equations suggested in [7]. One of the drawbacks of the method of a dynamic thermocouple is its destruction in a plasma jet when heated above 1300°C. On the other hand, the higher the temperature of heating of the thermocouple, the more precise the temperature measurement of the plasma jet.

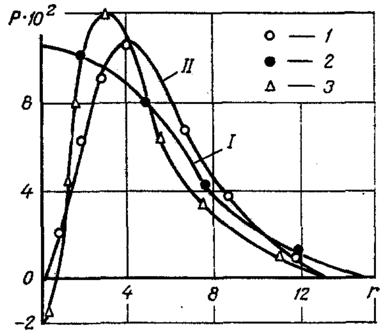

Fig. 3. Radial distributions of dynamic pressure in the plasma jet at an air flow rate of 5 g/sec: 1, 2) 30 mm from the nozzle cut of the plasmotron; 3) 20 mm; I) air + 3% CH_4; II) air; $P \cdot 10^2$ N/m^2.

Replacement of the destroyed thermocouple by a new one leads, as a rule, to an increase in the random measurement errors owing to differing junction diameters, nonuniformity of the electrode material, and inaccuracy in the placement of the thermocouple junction relative to the plasma jet. When measuring temperature profiles in a jet these errors hinder the explanation of the results obtained. The device developed for the temperature measurement (Fig. 1) entirely eliminated the destruction of the thermocouple and made it possible to obtain heating curves in a wide temperature range. The mechanism for the movement of the thermocouple and the electromagnets relative to the axis and cut of the plasmotron nozzle consisted of a coordinator. The thermocouple and the loop oscillograph were calibrated with an auxiliary resistor shown in the diagram.

Before the start of the experiment the duration of the stay of the thermocouple in the plasma jet sufficient for the junction to be heated to the melting temperature was set on an electronic time relay. When the "Start" button is pressed the time relay C1 fires, the N700 oscillograph is connected by the contacts C1.1, and power is supplied to the electromagnet EM1 through the contacts C1.2. The thermocouple is inserted into the plasma jet. The relay C2 is set for operation by the closing of the contacts C1.3. The signal from the thermocouple is supplied to the N700 loop oscillograph through the resistor R. The resistor and the galvanometer are chosen so that when the thermocouple junction is heated to 1300°C the response of the light spot on the N700 oscillograph occupies the entire width of the photographic paper. The voltage drop from the resistor R is fed to the direct-current amplifier (DCA), to the output of which the relay C3 is connected. The gain of the DCA is chosen in advance so that the relay C3 fires when the thermocouple junction is heated to 1300°C. When the relay C3 fires power is supplied through the contacts C3.1 to the relay C2, which through the contacts C2.1 disconnects the power supply to the N700 oscillograph, the electromagnet EM1 is de-energized by the opening of the contacts C2.2, and power is supplied to the electromagnet EM2 through the contacts C2.3. The thermocouple is removed from the jet. To eliminate the reintroduction of the thermocouple into the plasma jet because of a decrease in the signal from the DCA due to cooling of the junction outside the jet, the contacts C3.1 are blocked by the contacts C2.4. The lamp N1 signals the readiness of the device to make the next measurement. The effect of the connection of the DCA on the results of a measurement of the thermocouple temperature is insignificant, since the input resistance of the DCA is more than four orders of magnitude higher than the resistance of the resistor R, while the input capacitance of the amplifier is negligibly small.

The dynamic head of the jet was measured with a nonstationary Pitot tube. A detailed analysis of the errors arising in the measurement of the dynamic pressure by this method is presented in [8]. The axial, radial, and tangential velocity components were calculated from the measured values of the temperature, air flow rate, and dynamic head.

The results of the temperature measurement presented (Fig. 2) show the location of the region with the maximum temperature in the plasma jet depends on the air flow rate and on the admixtures of natural gas. With an increase in the air flow rate the size of the region of maximum temperatures reaches 8 mm at a distance of 30 mm from the nozzle cut for the modes of plasmotron operation investigated. At a greater distance from the nozzle cut of the plasmotron this region again approaches the axis. For small flow rates of the stabilizing air the highest temperature is found at the jet axis at any distance from the nozzle cut. The observed decrease in the axial temperature near the nozzle cut upon an increase in the flow rate of the stabilizing air agrees with the data of [9, 10], in which the results of spectroscopic measurements of the temperature of a nitrogen plasma are presented.

The measurements of the dynamic head were made in the same sections of the plasma jet as the temperature measurements, with the experimental conditions being unchanged. The experimental results showed the complex dependence of these profiles on the flow rate of the stabilizing air. A zone with a negative dynamic head develops near the nozzle cut at the jet axis at large flow rates of the stabilizing air (Fig. 3). At small air flow rates the maxima of the profiles of the dynamic head lie at the axis regardless of the distance to the nozzle cut.

The radial distributions of the dynamic head also depend on the construction of the gas-swirling disk [11]. Since natural gas is introduced into air plasma jets to intensify the process of heating of particles of the solid phase [3], we studied the temperature and velocity fields in the presence of admixtures of methane. The measurements were made with the introduction of 5% natural gas by volume. It was found that in a plasma jet when processes of methane combustion are taking place in it the maximum values of the temperatures and dynamic pressure lie at the jet axis (Figs. 2 and 3). To clarify the influence of the transverse injection of natural gas on the flow dynamics we introduced nitrogen into the jet instead of CH_4. The velocity fields do not undergo significant reorganization in this case. One can thus conclude that it is just the processes of combustion of the natural gas which affect the character of the flow of the plasma jet.

On the basis of the experimental data obtained the low values of the temperatures at the jet axis for large gas flow rates are explained by the presence of return flows of the gas. Thus, in calculating the processes of heating solid-phase particles in a swirled plasma jet with and without admixtures of combustible gases one must allow for the mutual variation of the temperature and velocity fields as a function of the gas flow rate. One can also assume that in heating particles some of them, having entered the region containing the return flow of gas, will undergo deeper phase transformations than the others.

NOTATION

T is the temperature, °K;
P is the pressure, N/m^2;
r is the distance from jet axis, mm.

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