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HYDRODYNAMIC STRUCTURE OF THE PLASMA GENERATOR ARC CHAMBER*

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Results of experimental research of the hydrodynamic structure of the plasma generator arc chamber are described. Special attention is given to the vortex stabilization of the electrical arc. The vector velocity angles and velocities in the high temperature region of the arc chamber space were measured in detail.

ГИДРОДИНАМИЧЕСКАЯ СТРУКТУРА РАЗРЯДНОЙ КАМЕРЫ ПЛАЗМОТРОНА

В работе даётся описание экспериментальных исследований гидродинамической структуры разрядной камеры плазмотрона. Особое внимание уделено исследованию вихревой стабилизации электрической дуги. Определёны угол вектора скорости и скорости высоконагретой среды в пространстве разрядной камеры.

I. INTRODUCTION

Today the high temperature chemical synthesis in pilot plans make frequent use of plasma generators. A brief survey of the types suitable for the chemical technology purposes is given, e.g., in Ref. [1].

One of the so far most important problems is the form and place of the chemical reactant supply into the plasma flow. It is possible to supply both the arc chamber and the plasma jet flowing out of the plasma generators. For solving the supply problem, the knowledge of the temperature and the hydrodynamic structure of both these spaces is needed. While there exists relatively enough experimental and theoretical information about plasma temperature, the knowledge of the hydrodynamic structure is very poor.

The presented article describes some experimental results dealing with the hydrodynamic structure of the arc chamber plasma flow. The main information on the structure of the free plasma jet is in Refs. [2], [3].

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II. EXPERIMENTAL EQUIPMENT

For the experimental research there has been used a plasma generator with a relatively long, electrically neutral arc chamber [4]. Its modification for arc chamber processes research is in Fig. 1. The position of the cathode K is variable during the plasma generator operation and so the electrical arc length can be

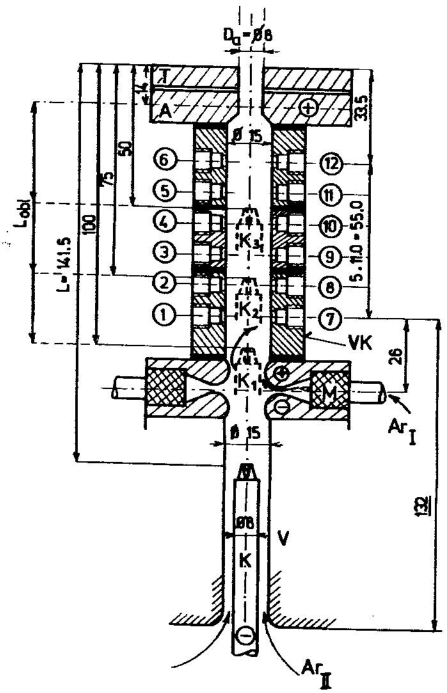

Fig. 1. Experimental plasma generator for research of arc chamber processes.

changed. The measured lengths are represented by the symbols K_1 ... K_3. If the arc chamber of 15 mm dia 12 measuring apertures marked by numbers in circles are placed. The chamber is constricted by the anode A followed by the nozzle T, both having the same 8 mm dia. The argon may be supplied either tangentially (Ar_I) or axially (Ar_{II}).

For static pressure measurements and for measurements of friction losses uncooled static probes are used placed in the measuring holes. The velocity and the angle of the velocity vector α in the near wall region (at a distance $\approx (0.3 \div 0.5)$ mm from the wall) were measured by means of special uncooled "T" type probes [5]. The head pressure radial profiles and angle of velocity vector in the arc chamber were measured with miniature intensively cooled cylindrical probes of 1.5 mm dia [6].

III. RESULTS OF EXPERIMENTS AND ANALYSIS

During experiments the plasma generator was operated by a tangential supply of argon and by the position of the cathode K. A tangentialy directed inflow of argon created a vortex flow with the variable angle α (angle of the velocity deviation from the chamber axis) and the variable velocity v.

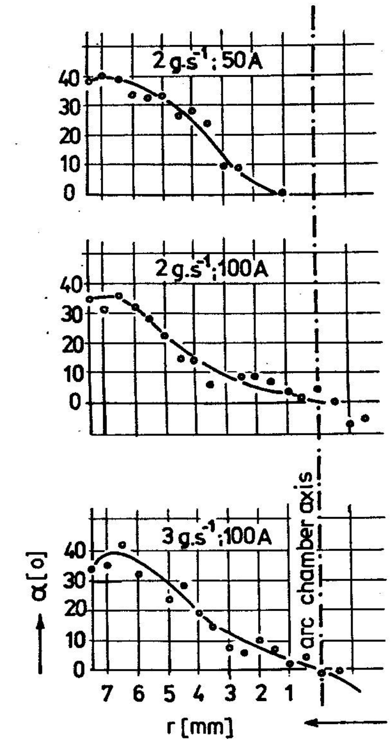

Fig. 2. Dependences of vector velocity angle α on arc chamber radius r — aperture No. 4.

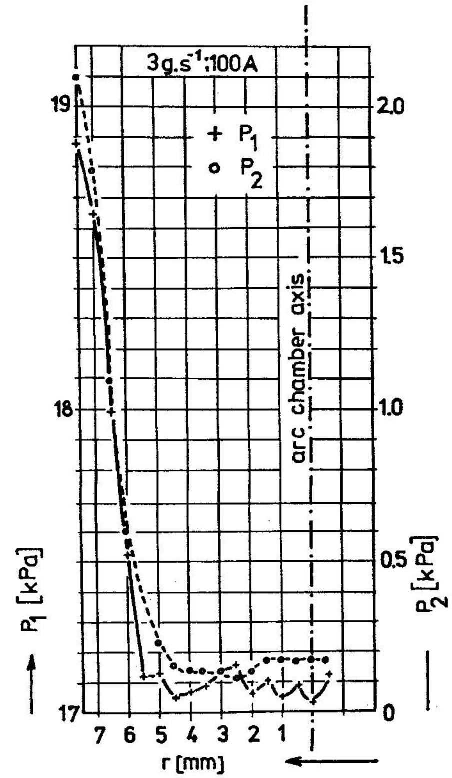

Fig. 3. Total (P_1) and dynamic (P_2) pressure proles — $I = 100$ A ; $G = 3\ gs^{-1}$ — aperture No. 4.

In Fig. 2 are given some results of the measurement in the aperture No. 4 in the form of dependences $\alpha(r)$ for the plasma generator operated by electric current of 50 and 100 A and a mass flow of argon 1.5 and 3.5 gs^{-1}. From these experimental values it follows that the highest angle α of about 40° is reached at the nearest distance of the arc chamber wall and that for $r \rightarrow 0$ the angle α decreases first rapidly, then slowly and at the axis becomes equal to zero.

The values of total (P_1) and dynamic (P_2) pressures along the arc chamber radius for one of the measured cases (100 A, 3 gs^{-1}) are given in Fig 3. The pressure P_1 and P_2 have their maxima at the wall followed by a region of a very high pressure gradient. In the central area ($r \leq 4.5$ mm) the values of P_1, P_2 are constant. Taking into account these results and the temperature profiles (estimated from the measured temperature in the chamber axis), we may calculate the velocity profiles. They are shown in Fig. 4.

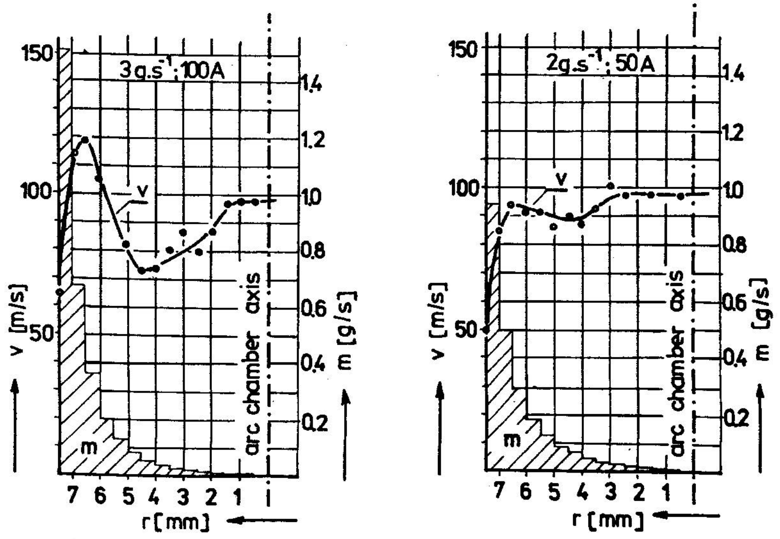

Fig. 4. Velocity (v) and sectional gas flow (m) profiles in the aperture No. 4.

The velocity profile for the case of 100 A, 3 gs^{-1} has a non-monotonous development with the peak maximum by the wall, followed by the minimum, which probably determines the boundary of the arc region and the region of the cold gas flow. A relative small rise in the velocity was indicated near the arc chamber axis at a distance of $r = 0 \div 1.5$ mm. When both the current and the gas flow are decreased (50 A, 2 gs^{-1}) the velocity profile is almost flat. Calculating sectional balances for both cases in Fig. 4, we obtain equal and surprising results. While in the arc region $r \approx 0 \div 3$ mm there flows only about $3 \div 4$ % of the total gas mass flow G, in the annular space near the wall having a thickness 0.5 mm there flows about 50 % G. The sectional gas mass flow (m) profile is independent from the velocity profile — as may be seen in Fig. 4.

Considering that in the near wall region there flows through the highest amount of the gas and the fact that this region has a determining role for the pressure losses due to friction (which are multiples of those calculated by analogy from the high temperatures fluid flow), special "T" shaped probe has been used for determining the wall chamber region. In the wide region of the working parameters of the plasma generator the angle of the velocity vector and the velocity (exactly the dynamic pressure) at a distance $0.3 \div 0.5$ mm from the wall have been measured. The results of the change of α for the plasma generator operation with $I = 50$, 100 and 150 A ang $G = 0.5 \div 3.5$ gs^{-1} are summarized in Fig. 5. Numbers of the

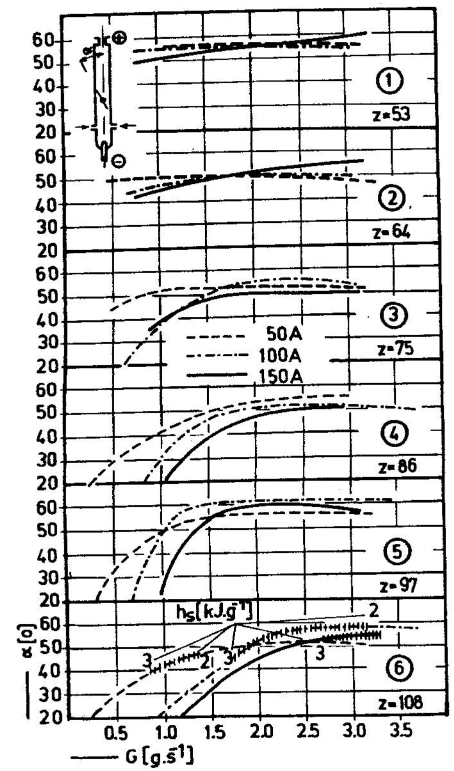

Fig. 5. Values of angle α at a distance $0.3 \div 0.5$ mm from chamber wall.

measuring apertures are located in a circle in the upper right-hand corner of each diagram. Below is written the distance (z) between the hole and the cathode.

For the given tangential gas supply system and the shape of the vortex chamber M — see Fig. 1 — the vortex flow has been determined. Vortex streamlines of a spiral form have at the distance of about 30 mm from the gas supply — aperture No. 1 — the angle of the spiral rise $\alpha = 50$—60°. The same angle has been measured at aperture No. 2, independently of the value of the arc current and the argon mass flow.

With an increasing distance from the cathode in the region of $G < (1.5—2.0)\ gs^{-1}$ there is a quick drop of the angle α. The damping of the vortex flow is essential only up to the aperture No. 4 and is more perfect for higher values of I.

The comparison of the apertures No. 4 and No. 6 showed that — from the point of reaching a straight plasma flow from the exit nozzle — only the chamber length up to the aperture No. 4 is sufficient and that the rest of its length up to the anode brings about only greater heat losses due the heat transfer to the chamber wall.

A similar research into plasma generators with shorter chamber lengths has also been done; its results are given in [8].

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