INFLOW OF A LIQUID JET VACUUM SEAL

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The possibility of the vacuum filling of the transfer opening of a seal by a jet of liquid in the form of a thin film is investigated. The seal is intended for enabling a high-power electron beam to emerge into the atmosphere.

The increase in the power of electron guns in which the electron beam emerges into the atmosphere is of interest from the point of view of constructing ionization lasers, technological equipment for cutting, welding, and melting metals, plasma chemistry, etc. Existing devices for extracting the electron beam into the atmosphere pass extremely high pulsed currents, but the average or continuous power withdrawn through their electron beam remains low, much less than the power of modern electron guns. In devices for extracting the electron beam through thin metal foils the average current density is mainly determined by the heat dissipation from the foil and is of the order of 10^{-4} A/cm^2 [1]. In devices with differential pumping and with transverse gas jets the difficulties involved in pumping out the inflowing gas and the performance of pumping devices prevent the diameter of the transit opening from being increased (it is usually fractions of a millimeter [2]), while the small diameter of the transit opening limits the value of the electron current. The average power of such equipment in which the electron beam emerges into the atmosphere does not exceed 30 kW [2].

A vacuum gap, the transit opening of which is covered by a jet of liquid in the form of a thin continuous film has a much greater transmitting capacity. In fact, assuming that the maximum electron current density passing through the jet is determined by the heating of the liquid to the boiling point, we obtain that one can extract through a jet of liquid with a velocity of 10^2 m/sec, corresponding to a pressure head of $\approx 50 \cdot 10^5$ N/m^2, and a thickness of 0.1 mm, an electron current of greater than 0.1 A per centimeter width of the jet for a beam energy of 150 keV. The transparency of the liquid film under these conditions is about 50%. Estimates carried out for liquids allow of heating up to 50°.

In this paper we experimentally investigate the possibility of a vacuum filling of the transit opening of a seal by a jet of liquid in the form of a thin film. As shown in Fig. 1, the model of the seal, on which the experiments were carried out, consists of three mutually ground components 1, 2, and 3. The transit opening of the seal, formed by the inner walls of components 1 and 2, is covered by the jet of liquid 4, emerging from channel 5 between components 2 and 3 through a slit, whose width is established using changeable washers 6. The channel 5 is connected to a high-pressure reservoir.

The jet separates regions of high pressure $p_1 = 10^5$ N/m^2 at low pressure $p_2 = 1\text{-}0.01 \cdot 10^5$ N/m^2. The pressure drop $\Delta p = p_1 - p_2$ deflects the jet downwards towards the low-pressure region, and after intersecting the transit opening is incident at an angle of φ on the upper surface of component 1, after which it is reflected towards the high-pressure side. The jet forms a cylindrical surface the radius of curvature R of which is found from Bernoulli's equation $P = 1/2\rho V^2$, and the expression for the centrifugal force $\Delta p = \rho d V^2/R$ after eliminating the product of the liquid density and the square of the velocity V: $R = 2dP/\Delta p$, where P is the excess pressure of the liquid in the reservoir, and d is the thickness of the jet. In order that the jet should overlap the transit opening of the seal its width must be less than R, i.e., the pressure head P must be fairly high.

We used water as the working liquid. The thickness of the jet was not measured directly. Its value could be judged from the width of the slit forming the jet, which varied from 0.05 to 0.20 mm. The dimension of the slit along the flow was 0.2 mm. The width of the jet was 20-30 mm. Components 2 and 3 were not changed during the experiments, but component 1, which determined the shape of the receiving surface, the angle of incidence φ, and the size of the transit opening, was changed. By specifying the slope α of the receiving surface of component

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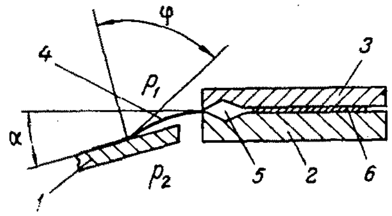

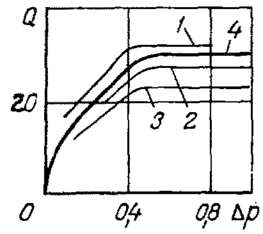

Fig. 1 Fig. 2

Fig. 1. Sketch of the liquid jet seal: 1, 2, and 3) components forming the body of the seal; 4) jet of liquid in the form of a thin film; 5) channel in the body of the seal; and 6) washer.

Fig. 2. Dependence of the flow through the seal Q, N·m/sec, on the pressure drop across it Δp, 10^5 N/m^2, for several values of the thickness of the liquid jet d, mm, the value of the pressure head P, N/m^2, and the angle α, degrees: 1) d = 0.08, P = $20 \cdot 10^5$, α = −5°; 2) d = 0.06, P = 20 and 40, α = 25°; 3) d = 0.1, P = 20, α = 10°; 4) flow velocity through a circular opening in a thin foil of area 1.5 mm^2.

1 to the initial direction of the jet, we were able to vary the angle incidence φ of the jet from 0 to 75°. The dimensions of the transit opening were as follows: width 0.5, 1, and 2 mm, length 10 mm.

For the chosen value of the width of the slit forming the jet, the pressure of the liquid in the reservoir ($P = 1\text{–}40 \cdot 10^5$ N/m^2), and the shape of the receiving surface, we measured the velocity of flow Q through the seal as a function of the pressure drop Δp in the jet. Figure 2 shows typical curves (1, 2, and 3) of the flow velocity Q(Δp) through the seal for several values of the jet thickness d, the pressure head P, and the angle α. For comparison we also show a curve (4) of the flow velocity through a circular opening in a thin foil of area 1.5 mm^2. The transit opening of the seal in these experiments had the shape of a rectangle of dimensions 1×10 mm, and a jet width of 20 mm. Comparison of the curves shows that the flow through the jet of liquid in the form of a thin film, covering the transit opening of the seal, over a wide range of pressure drops $\Delta p = 0.05\text{–}1 \cdot 10^5$ N/m^2 occurs as through an opening of constant diameter. In the range $P = 5\text{–}40 \cdot 10^5$ N/m^2, Q depends only slightly on the pressure head. Q increases only slightly as the angle of incidence φ of the jet on the receiving surface increases, and as the thickness of the jet decreases. A further reduction in the pressure head of the jet below $P_* = (2\text{–}3) \cdot 10^5$ N/m^2 causes a sharp reduction in the flow by more than three orders of magnitude. However, the jet retains a very low pressure drop for such pressure heads, amounting to, e.g., $\Delta p \approx 0.1 \cdot 10^5$ N/m^2 for $P = 2 \cdot 10^5$ N/m^2 and a width of the transit opening of 1 mm.

The slope of the receiving surface α to the initial direction of the jet to a considerable extent determines the area of the surface of the jet. For large positive values of α the dimensions of the jet with respect to the flow are practically independent of the pressure head and the pressure drop in the jet. For example, curve 2 in Fig. 2 (α = 25°) corresponds to a jet width with respect to the flow of 1.5–2 mm. For negative angles α, as shown in Fig. 1, the width of the jet to the flow increases sharply as the pressure drop in the jet Δp decreases for a fixed pressure head, since the radius of curvature of the jet R is inversely proportional to Δp. Curve 1 in Fig. 2 was obtained for a jet width varying from 3 mm to 25 mm, but it differs only slightly from curve 2. Hence we see that the flow depends only slightly on the area of the jet surface. Visual observations on the jet showed that in the range $P = (1\text{–}10) \cdot 10^5$ N/m^2 over the whole area of the surface the jet remains transparent with a smooth surface in reflected light. The jet becomes cloudy for large values of the pressure heads.

Observations of the interaction between the jet and the receiving surface, and also of the motion of small drops over the receiving surface enabled us to conclude that the flow when $P > P_*$ occurs primarily along the lines of impact of the jet with the opposite wall of the body of the gap. Sticking of the jet to the receiving surface, which occurs for small

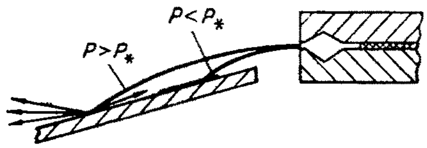

Fig. 3. Two types of interaction between the jet and the receiving surface for large pressure heads ($P > P_*$) and small pressure heads ($P < P_*$).

pressure heads, can be removed for $P > P_*$ by reflection of the jet and spraying into fine drops, as shown in Fig. 3. In this case the small liquid roller along the line of impact from the low-pressure side disappears.

In these experiments, excluding the edge regions, the line of impact is situated perpendicular to the direction of motion of the jet. The critical value on the pressure head was increased when the receiving surface was placed such that the line of impact made a small acute angle with the direction of motion of the jet.

Investigations of the collision between a solid and liquid carried out previously [3] showed that for high velocities of deformation the liquid behaves as a brittle body, forming fragments and cracks. For water the critical velocity is ∿10 m/sec, which corresponds to the critical pressure head obtained in the experiments. Measurements of the flow velocity through the seal for $P > P_*$ gave a value of the order of the thickness of the jet (0.1-0.2 mm) for the width of the part of the jet disintegrated along the line of impact.

It follows from the above that one can expect a considerable increase in the critical head when using high-molecular-weight polymers as small additions to the liquid due to their property of increasing the impact stability of the liquid [4].

NOTATION

p_1 and p_2, pressure of the gas on the upper and lower sides of the seal, respectively, N/m^2; $\Delta p = p_1 - p_2$, pressure drop across the seal, N/m^2; P, excess pressure of the liquid in the reservoir or the pressure head of the jet, N/m^2; P_*, critical value of the pressure head of the liquid jet, N/m^2; R, radius of the cylindrical surface formed by the jet of liquid when moving, cm; V, velocity of the jet, m/sec; d, thickness, cm; ρ, density, kg/m^3; Q, flow velocity of the gas through the seal, N·m/sec; α, angle between the upper surface of component 1 of the seal (Fig. 1) and the initial direction of the jet, deg; and φ, angle of incidence of the jet of liquid on the surface of component 1 (Fig. 1), deg.

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