Journal of Applied Mechanics and Technical Physics, Vol. 45, No. 5, pp. 639–646, 2004

STATIONARY DISCHARGE SUSTAINED BY ELECTRON THERMAL CONDUCTION FOR EMERGENCE OF A MAGNETIC FLUX THROUGH AN INSULATOR SURFACE

S. F. Garanin and D. V. Karmishin

UDC 533.95:537.84

This paper considers a stationary surface discharge that arises when a magnetic flux emerges through an insulator surface (H-pushed discharge). It is assumed that the heat flux in the discharge is determined only by the electron thermal conductivity of the ionized vapor of the insulator and the Nernst effect. The main parameters of the discharge and the structure of the current layer are determined for the case of strong magnetic fields (above 0.1 MOe) *and an aluminum oxide insulator.*

Key words: *magnetic flux, H-pushed discharge, heat flux, ionized vapor of insulator.*

Introduction. In the development of various powerful pulsed systems, a necessity arises to transfer electromagnetic energy through an insulator surface. Figure 1 shows diagrams of units in which there is energy transfer to vacuum, a plasma, and a liner. The operation of such units can involve difficulties due to surface breakdown of the insulator and its subsequent transition to the stage of a pseudo-stationary discharge (H-pushed discharge; this term arose from the fact that the ponderomotive force $[\boldsymbol{jH}]/c$ pushes the conducting ionized vapor away from the insulator surface; see Fig. 2). In this case, part of the current supplied to the installation is branched off to the discharge, resulting in a decrease in the power transmitted to the load through the insulator surface.

The occurrence of an H-pushed discharge and its effect on the corresponding units were studied in [1, 2]. A stationary discharge (Fig. 2) can arise because the plasma outflow from the discharge zone under the action of a ponderomotive force is compensated by vaporization of the insulator material by the heat flow from the plasma. In [1], the heat flow was determined by "black radiation" from the ionized vapor, and in [2], it was determined by radiation from the entire plasma (depended on the geometry of the system).

The effect of an H-pushed discharge can be reduced by attenuating the radiation flows, e. g., by changing the installation geometry, using special shields to protect from radiation, etc. However, in the case of a discharge even without radiation, the discharge can further be sustained by the electron thermal conductivity of the plasma and lead to branching of part of the current from the load and to the entry of the insulator material plasma to the load volume. In the absence of radiation, the deleterious effect of these processes is weaker. In this sense, discharges sustained by electron thermal conductivity are characterized by minimum values of the branched current and the insulator material flow into the load volume.

In the present paper, we analyze an H-pushed discharge for a ceramic insulator (Al_2O_3) in the range of strong magnetic fields (above 0.1 MOe) in the absence of radiation. For ionized insulator vapor, the Lorentzian plasma approximation is used. The plasma is considered magnetoactive. The effect of magnetization on the thermal and electric conductivity is taken into account. In addition, allowance is made for the Nernst effect, whose contribution to the heat flux is of the same order as that of the electron thermal conductivity and whose contribution to the electric field is similar to that of the electric resistance of the plasma.

Institute of Experimental Physics, Sarov 607190; sfgar@vniief.ru. Translated from Prikladnaya Mekhanika i Tekhnicheskaya Fizika, Vol. 45, No. 5, pp. 32–40, September–October, 2004. Original article submitted July 17, 2003.

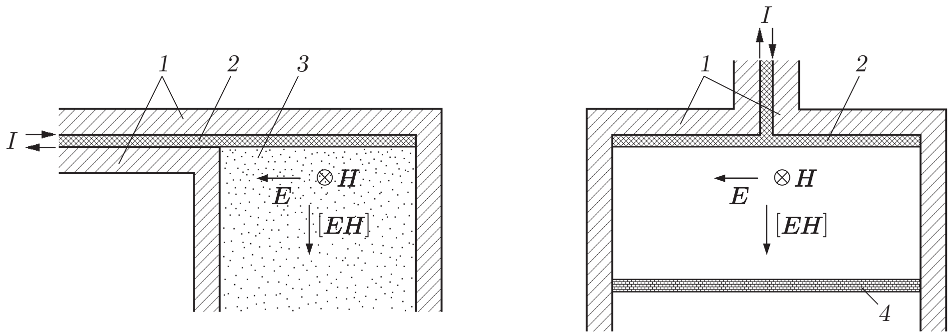

Fig. 1. Diagrams of units with electromagnetic energy transfer through the insulator surface: 1) conducting walls; 2) insulator; 3) plasma (or vacuum); 4) and liner.

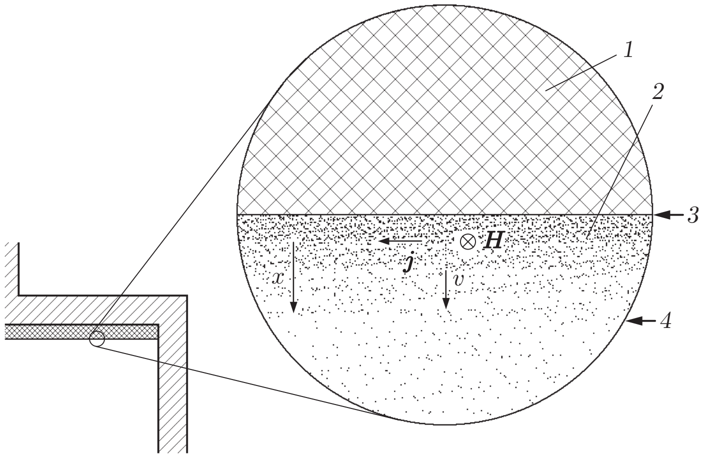

Fig. 2. Discharge zone: 1) unvaporized insulator; 2) insulator vapor; 3) beginning of the discharge zone; 4) end of the discharge zone.

Basic Equations. Under typical experimental conditions, the discharge layer thickness is small compared to the installation dimensions (about 0.1 cm at $H \approx 10^5$ Oe and decreases with increase in H — see below); therefore, the time of change in the vaporization regime is small compared to the times of change in the parameters affecting the current layer. Consequently, the discharge can be considered stationary. Because discharge layer thickness is smaller than the characteristic dimensions of the insulator, the curvature of the insulator surface can also be ignored. Thus, we obtain a one-dimensional stationary problem in which all parameters depend only on the normal coordinate.

The current layer thickness is relatively small, and in calculations for a particular installation, it can be replaced by an infinitely narrow jump of MHD parameters. Nevertheless, to obtain the values of these parameters at the exit from the current layer, it does not suffice to use only the integral conservation laws but it is necessary to know the structure of this layer.

In the problem considered (see Fig. 2), the magnetic and electric fields are perpendicular to each other and are parallel to the insulator surface and the heat flux is determined by the electron thermal conductivity and the Nernst effect, i.e.,

$$q = -\chi \frac{dT}{dx} + \frac{b}{e} Tj,$$

where χ is the electron thermal conductivity, T is the temperature, e is the electron charge, j is the current density, and the coefficient b/e describes the Nernst effect. The problem allows arbitrary repeated ionization of the insulator vapor.

The problem is described by the following system of one-dimensional stationary MHD equations:

$$\rho v = \text{const}, \qquad \rho v^2 + P + H^2/(8\pi) = \text{const},$$

$$\rho v\Big(\frac{v^2}{2} + w\Big) + \frac{c}{4\pi}\, EH - \chi\,\frac{dT}{dx} + \frac{b}{e}\,Tj = \text{const}, \qquad E = \text{const}, \tag{1}$$

$$\frac{dH}{dx} = -\frac{4\pi}{c}\,j, \qquad E = \frac{j}{\sigma} + \frac{1}{c}\,vH - \frac{b}{e}\,\frac{dT}{dx},$$

where $\rho(x)$, $v(x)$, $P(x)$, $H(x)$, $w(x)$, $E(x)$, $\chi(x)$, $b(x)$, $T(x)$, $j(x)$, and $\sigma(x)$ are the current values of the density, velocity, pressure, magnetic field strength, specific enthalpy, electric field, electron thermal conductivity, the coefficient describing the Nernst effect, temperature, current density, and the conductivity of the insulator vapor, respectively. System (1) represents the conservation laws for the mass, momentum, and energy fluxes, two Maxwell's equations, and Ohm's law. For a magnetoactive plasma,

$$\sigma = \frac{3T^{3/2}}{4\sqrt{2\pi m}e^2 LZ\alpha}, \qquad \chi = \frac{3T^{5/2}\gamma}{4\sqrt{2\pi m}e^4 LZ}, \tag{2}$$

where m is the electron mass; L is the Coulomb logarithm; Z is the mean square ion charge; the quantities α, b, and γ in formulas (1) and (2) correspond to $\alpha_\perp$, β_Λ^{uT}, and $\chi_\perp^e$ from [3] and are evaluated from the approximate formulas

$$\alpha = 1 - \frac{\alpha_1' y^2 + \alpha_0'}{\Delta}, \quad b = \frac{y(\beta_1'' y^2 + \beta_0'')}{\Delta}, \quad \gamma = \frac{\gamma_1' y^2 + \gamma_0'}{\Delta}, \quad \Delta = y^4 + \delta_1 y^2 + \delta_0, \tag{3}$$

where $y = \omega_e \tau_e$ is the degree of magnetization of electrons. The coefficients (α_0', α_1', etc.) are chosen for the ion charge $Z \to \infty$ by sequentially using the Lorentzian plasma approximation because in the discharge there is a rather high temperature, and hence, the degree of ionization.

The transfer coefficients of a magnetoactive plasma are linked to the corresponding coefficients of a Lorentzian nonmagnetized plasma σ_L and χ_L by the relations $\chi = \gamma\chi_L/\gamma_0 = 0.08\gamma\chi_L$ and $\sigma = \alpha_0\sigma_L/\alpha = 3\pi\sigma_L/(32\alpha)$, where α and γ, according to (3), are determined by the plasma magnetization y and depend on T, ρ, and H, and the values of α_0 and γ_0 correspond to the zero degree of magnetization.

The subscript 0 indicates the values at the beginning of the discharge zone, and the subscript 1 indicates the values at the end of the discharge zone. Because the insulator density is higher than the vapor density, we have $v_0 = 0$, and at the end of the current layer, the vapor is accelerated to the outflow velocity of the magnetic lines of force $v_1 = cE/H_1$. At the entrance to and exit from the current layer, the heat flux and current density tend to zero; therefore, here $dT/dx = 0$ and $dH/dx = 0$. System (1) can now be written as

$$\rho v = \rho_1 v_1, \qquad \rho v^2 + P + \frac{H^2}{8\pi} = \rho_1 v_1^2 + P_1 + \frac{H_1^2}{8\pi} = P_0 + \frac{H_0^2}{8\pi},$$

$$\rho v\Big(\frac{v^2}{2} + w\Big) + \frac{c}{4\pi}\, EH - \chi\,\frac{dT}{dx} - \frac{bc}{4\pi e}\,T\,\frac{dH}{dx} = \rho_1 v_1\Big(\frac{v_1^2}{2} + w_1\Big) + \frac{c}{4\pi}\, EH_1 = \frac{c}{4\pi}\, EH_0, \tag{4}$$

$$-æ_H\,\frac{dH}{dx} + vH = cE + \frac{cb}{e}\,\frac{dT}{dx},$$

where $æ_H = c^2/(4\pi\sigma)$ is the magnetic diffusivity.

Assuming the ionized insulator vapor to be a gas with an adiabatic exponent γ_T and using an approximate calculation method in the region of repeated ionization (Saha's equation with repeated ionization) [4] and the formulas for the thermal and electric conductivities of a nonmagnetized Lorentzian plasma [7] χ_L and σ_L, we obtain the interpolation formulas $P \approx T^m\rho^n$, $\chi_L \approx T^{1+i}\rho^j$, and $æ_{HL} \approx T^{-i}\rho^{-j}$ and the effective adiabatic exponent in a certain range of temperatures and densities for a particular type of insulator. In this connection, the question arises of whether the equilibrium formulas of thermodynamics are adequate for describing the examined plasma in the absence of radiation. To answer this question, it is necessary to compare the plasma radiation characteristics in the temperature and density ranges of interest calculated using the coronal model [5] and the thermodynamic equilibrium approximation. The approach that will yield lower intensity is appropriate. In our case ($T \approx 10$ eV and $\rho \approx 10^{-4}$ g/cm^3), the radiation intensity, according to [6], differs *a priori* from the quadratic dependence on density, which is necessary for the coronal model, and, therefore, the approach of local thermodynamic equilibrium should be valid. Let us use the system of units g, cm, and μsec, MOe for the magnetic field, and eV for the temperature. For a ceramic insulator from aluminum oxide at temperatures of 3–30 eV and densities of 10^{-5}–10^{-3} g/cm^3, we obtain the following approximate formulas:

$$P(T,\rho) = 3.8\cdot 10^{-2} T^m \rho^n \qquad (m = 1.417, \quad n = 0.917),$$

$$\chi_L(T,\rho) = 1.84\cdot 10^{-8} T^{1+i} \rho^j \qquad (i = 0.825, \quad j = 0.158),$$

$$æ_{HL}(T,\rho) = c^2/(4\pi\sigma_L(T,\rho)) = 0.173 T^{-i}\rho^{-j}, \qquad \gamma_T = 1.2.$$

The values of the quantities calculated by these formulas in the indicated range of temperatures and densities differ from those calculated using Saha's equation [4] and the refined Coulomb logarithm [8] by not more than 5%.

According to the previously proposed method for solving similar problems [9], the measurements units for the temperature $[T]$ and density $[\rho]$, which determine the characteristic parameters of the problem, are found from the condition of equality of the magnetic diffusivity $æ_H$ and the thermal diffusivity $æ_{TL} = (\gamma_T - 1)\chi_L T/(\gamma_T p)$ (assuming that the characteristic plasma magnetization $y \approx 1$, which is a consequence of equality of the magnetic diffusivity and thermal diffusivity; for definiteness of the choice of measurement units, we equate the values of the magnetic diffusivity and thermal diffusivity for $y = 0$) and from equality of the thermal pressure to magnetic pressure (for definiteness, as a unit of measurement for pressure we use the magnetic pressure at the exit from the discharge zone):

$$[P] = P([T],[\rho]) = H_1^2/(8\pi), \qquad æ_{HL}([T],[\rho]) = æ_{TL}([T],[\rho]).$$

Solving these two equations, we obtain

$$[T] = 101 H_1^{0.415}, \qquad [\rho] = 8.37\cdot 10^{-4} H_1^{1.54}. \tag{5}$$

Let us introduce the dimensionless variables

$$t = \frac{T}{[T]}, \quad r = \frac{\rho}{[\rho]}, \quad u = \frac{v}{v_1}, \quad h = \frac{H}{H_1}, \quad p = \frac{P}{[P]} = \frac{P}{H_1^2/8\pi} = t^m r^n, \quad \xi = \frac{x}{[x]}, \tag{6}$$

where $[x]$ is found from the relation $[x] = æ_{HL}([T],[\rho])/v_1$, which, in view of (5), yields

$$[x] = 1.71\cdot 10^{-3}\sqrt{r_1/\mu}\, H_1^{-0.816}. \tag{7}$$

For convenience, we introduce the dimensionless parameters

$$\beta = 8\pi p_1/H_1^2, \qquad \mu = 8\pi\rho_1 v_1^2/H_1^2 \tag{8}$$

and the constant $g = 2\gamma_T/(\gamma_T - 1)$ and proceed to considering system (4). We substitute the relations $cE = v_1 H_1$ and $w = \gamma_T p/((\gamma_T - 1)\rho)$ into the third and fourth equations of system (4) and divide the first equation by $v_1[\rho]$, the second by $H_1^2/(8\pi)$, the third by $v_1 H_1^2/(16\pi)$, and the fourth by $v_1 H_1$. From the first equation, we obtain the relationship between the dimensionless density and the velocity $r = r_1/u$. Substituting this relation into the other three equations (4), we arrive at the system

$$\begin{gathered}
\mu u + r_1^n t^m u^{-n} + h^2 = \mu + \beta + 1, \\
\mu u^2 + g r_1^n t^m u^{1-n} + 4h - 0.08\gamma g r_1^j t^{1+i} u^{-j}\,\frac{dt}{d\xi} - \sqrt{g}\, bt\,\frac{dh}{d\xi} = \mu + 4 + g\beta, \\
-\frac{32\alpha}{3\pi}\, r_1^{-j} t^{-i} u^j\,\frac{dh}{d\xi} + uh = 1 + \frac{b\sqrt{g}}{4}\,\frac{dt}{d\xi}.
\end{gathered} \tag{9}$$

Here t, u, and h are unknown functions of the variable ξ and μ, β, and r_1 are parameters. From the first and second equations of system (9), setting $u = 0$ and ignoring derivatives, we obtain the following expressions for the magnetic field and pressure in the insulator

$$h_0 = (\mu + 4 + g\beta)/4, \qquad p_0 = \mu + \beta + 1 - h_0^2.$$

In the chosen units of measurement, the degree of magnetization of the insulator material plasma is expressed as

$$y = \omega_e \tau_e = \frac{3\pi}{32\sqrt{2}} \sqrt{\frac{\gamma_T}{\gamma_T - 1}} \Big(1 + \frac{1}{Z}\Big) r_1^{j-n} t^{1+i-m} u^{n-j} h. \tag{10}$$

Since we use the Lorentzian plasma approximation, considering Z large enough, for $\gamma_T = 1.2$ we obtain

$$\omega_e \tau_e = 0.51 r_1^{j-n} t^{1+i-m} u^{n-j} h.$$

Method of Solution. Eliminating the magnetic field h from Eqs. (9), we obtain the system

$$a_1 \frac{dt}{d\xi} + b_1 \frac{du}{d\xi} = c_1, \qquad a_2 \frac{dt}{d\xi} + b_2 \frac{du}{d\xi} = c_2,$$

which contains the temperature and velocity as functions of the coordinate ξ. This system can be reduced to the form

$$\frac{dt}{d\xi} = \frac{c_1 b_2 - b_1 c_2}{a_1 b_2 - b_1 a_2}, \qquad \frac{du}{d\xi} = \frac{a_1 c_2 - c_1 a_2}{a_1 b_2 - b_1 a_2}$$

provided that the determinant $a_1 b_2 - b_1 a_2$ differs from zero. Since the right sides of the equations do not contain ξ, the order of the system can be reduced. We divide one equation by the other and integrate the equation

$$\frac{dt}{du} = \frac{c_1 b_2 - b_1 c_2}{a_1 c_2 - c_1 a_2} \tag{11}$$

with the boundary conditions $u_0 = 0$, $t_0 = 0$, $u_1 = 1$, and $t_1 = (\beta r_1^{-n})^{1/m}$ and the three free parameters μ, β, and r_1.

The initial and final points are singular, exit from them was performed using the expansion $t(u)$. Exit from the terminal point is uniquely determined by the parameters and boundary conditions, and exit form the initial point contains an arbitrariness due to the uncertainty of the initial conductivity distribution in the insulator (and, hence, the possibility of subsequent breakdown) and a possible nonzero value for the heat flux form the discharge zone.

The uncertainty of the exit from the initial point is eliminated if we take into account that the expansion near the initial point corresponds to the primary heating of the plasma due to electron thermal conduction (i.e., the Joule heat release in this region is small compared to the heating due to thermal conduction, and the heat flux on the boundary of the discharge zone is equal to zero) and in the vicinity of the initial point, the plasma is not magnetized. At the initial point, $t = 0$, $u = 0$, $h = h_0$, and $p = p_0$, and at the exit from it, we can approximately set $p = r_1^n t^m u^{-n} = p_0$, whence $u = r_1 p_0^{-1/n} t^{m/n}$. Since the initial heating of the insulator is due to electron thermal conduction, from the second equation of system (9) we obtain $r_1^j t^{1+i} u^{-j}\, dt/d\xi = r_1^n t^m u^{1-n}$. Substituting the expression for u into the latter formula and integrating the result over ξ, we obtain

$$t(\xi) = \Big[\Big(2 + i - \frac{m}{n}(1+j)\Big) r_1 p_0^{\frac{n-1-j}{n}}\Big]^{\frac{1}{2+i-m(1+j)/n}} \xi^{\frac{1}{2+i-m(1+j)/n}}.$$

Then, $u(\xi) = r_1 p_0^{-1/n} (t(\xi))^{m/n}$ and integrating the third equation of system (9), we have

$$h(\xi) = h_0 - p_0^{j/n} \Big[\Big(2 + i - \frac{m}{n}(1+j)\Big) r_1 p_0^{\frac{n-1-j}{n}}\Big]^{\frac{ni-mj}{n(2+i)-m(1+j)}} \frac{(2+i)n - (1+j)m}{(1+i)2n - (1+2j)m} \xi^{\frac{(1+i)2n-(1+2j)m}{(2+i)n-(1+j)m}}.$$

The asymptotic behavior of the temperature with accuracy up to the next terms of expansion in ξ, which eliminates the uncertainty due to the possibility of breakdown in the specification of the initial conductivity distribution in the insulator, is obtained by substituting $u(\xi)$ and $h(\xi)$ into the first equation of system (9).

The expansion near the terminal point is determined by the exponential nature of the approach of the MHD parameters to their final values.

For the specified discharge regime, which can be characterized by a single parameter, for example, μ, in solving the equations, we needed to select the other two parameters (β, r_1) so as to obtain a solution with the specified boundary conditions. In this case, it was necessary to pass through the singular point corresponding to the vanishing of the numerator and denominator of (11) (at this point, the flow velocity becomes equal to thermal sound velocity $v^2 = \gamma P/\rho$). By changing one parameter, it is possible to achieve to arrive at this singular point

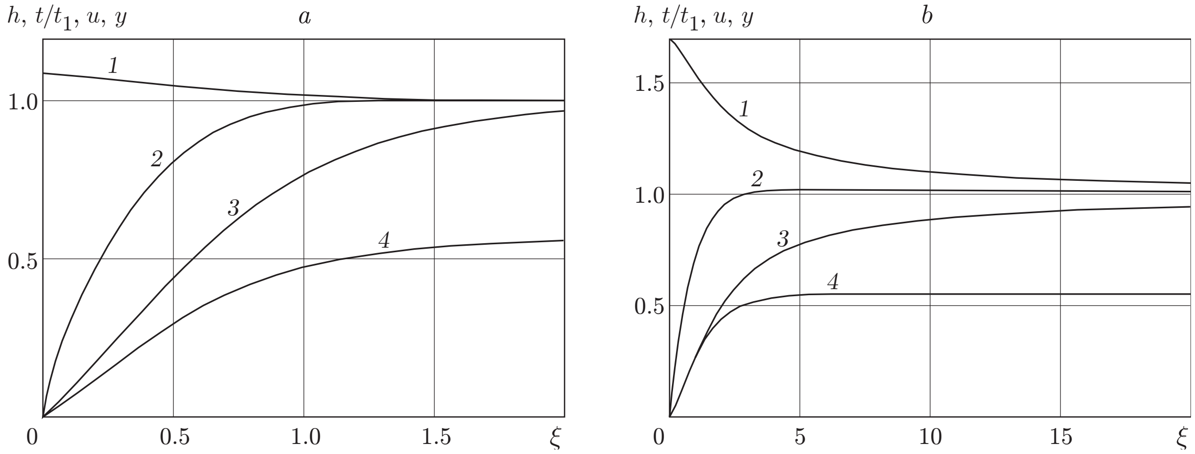

Fig. 3. Spatial distributions of the dimensionless MHD parameters for $\mu = 0.2$ (a) and 2 (b): curve 1 refers to h, curve 2 to t/t_1, curve 3 to u, and curve 4 to y.

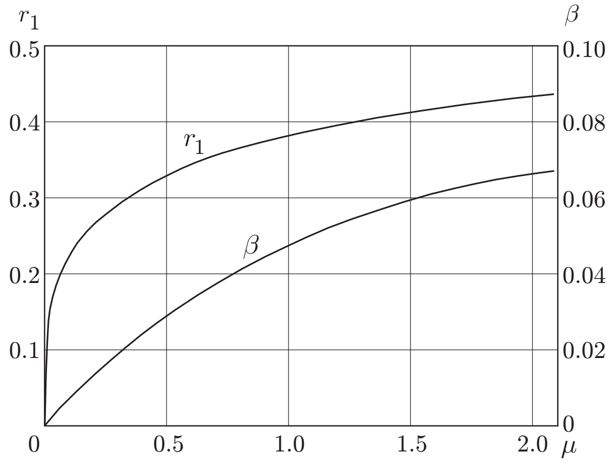

Fig. 4. Plots of the functions $\beta(\mu)$ and $r_1(\mu)$.

after exiting from the initial point by the specified expansion, and changing the other parameter, one can get from the terminal point to the same singular point. As a result of the solution, for each μ we obtain particular values of β and r_1, i.e., dependences $\beta(\mu)$ and $r_1(\mu)$ describing various discharge regimes.

Calculation Results. Figure 3 shows the structure of the current zone, i.e., curves of the dimensionless MHD parameters versus the coordinate x. Figure 4 gives curves of $\beta(\mu)$ and $r_1(\mu)$.

In the problem considered there is a limiting regime of insulator vaporization [1] similar to the Jouguet regime in combustion, in which, the velocity of the plasma escaping from the discharge is equal to the "total" sound velocity:

$$v_1^2 \leqslant c_1^2 \equiv \gamma P_1/\rho_1 + H_1^2/(4\pi\rho_1). \tag{12}$$

For the dimensionless variables, this limitation is expressed as

$$\mu \leqslant \mu_{\max} \equiv 2 + \gamma_T \beta.$$

The limiting regime corresponds to the calculated values $\mu_{\max} = 2.08$, $\beta_{\max} = 0.0675$, and $r_{1\,\max} = 0.439$. For the parameter values exceeding the maximum ones, the discharge ceases to be stationary, i.e., if the plasma boundary moves away from the insulator at a velocity exceeding the velocity calculated from formula (12) (for example, during acceleration of a light liner or for a discharge into vacuum), then a rarefaction wave is formed between this boundary and the plasma escaping from the discharge.

TABLE 1

Dimensionless Discharge Parameters

μ	β	r_1	h_0
0.01	0.0007024	0.1173	1.0046
0.1	0.006763	0.2215	1.0453
0.2	0.01298	0.2651	1.0889
0.5	0.02878	0.3306	1.2113
1	0.04766	0.3837	1.3930
1,5	0,05972	0,4147	1,5542
2	0.06675	0.4363	1.7003
2.08	0.06749	0.4392	1.7225

TABLE 2

The Main MHD Parameters versus Discharge Intensity for a Magnetic Field in the Insulator $H_0 = 1$ MOe

μ	H_1, MOe	v_1, km/sec	ρ_1, 10^{-4} g/cm^3	T_1, eV	E, kV/cm
0.01	0.995	20.11	0.975	2.408	20.02
0.1	0.957	45.87	1.731	7.762	43.88
0.2	0.918	58.74	1.945	10.76	53.94
0.5	0.826	81.15	2.059	15.66	66.99
1	0.718	103.2	1.927	19.16	74.06
1.5	0.643	118.5	1.759	20.41	76.25
2	0.588	130.7	1.612	20.58	76.86
2.08	0.581	132.4	1.591	20.54	76.89

The calculated values of the parameters μ, β, and r_1 and the corresponding values of the dimensionless h_0 are presented in Table 1. Table 2 gives the values of the magnetic field magnitude H_1, velocity v_1, density ρ_1, and temperature T_1 at the exit from the discharge, and the electric field E [kV/cm] calculated according to (5), (6), and (8) from the formulas

$$H_1 = H_0/h_0, \quad T_1 = t_1[T] = 101\beta^{0.706} r_1^{-0.647} h_0^{-0.415} H_0^{0.415}, \quad \rho_1 = 8.37 \cdot 10^{-4} r_1 h_0^{-1.54} H_0^{1.54},$$
$$v_1 = \sqrt{\frac{\mu H_1^2}{8\pi\rho_1}} = 6.9\Big(\frac{\mu}{r_1}\Big)^{0.5} h_0^{-0.23} H_0^{0.23}, \qquad E = \frac{v_1}{c}\, H_1 = 69\Big(\frac{\mu}{r_1}\Big)^{0.5} h_0^{-1.23} H_0^{1.23} \tag{13}$$

for a magnetic field in the insulator $H_0 = 1$ MOe.

Based on formulas (13), the following method for calculating an H-pushed discharge can be proposed. Using formulas (13) for the electric field with the initial fields E and H and data from Table 1, we find the parameter μ. Next, from Fig. 4 we obtain the values of β and r_1, h_0, and then, using the remaining formulas (13), we find all plasma parameters at the exit from the H-pushed discharge zone in the absence of radiation. These parameters can be specified as the boundary conditions in full MHD calculations of particular units and installations.

It reasonable to compare the H-pushed discharge regimes due to plasma radiation [1] and the discharge considered in the present study. Figures 5 and 6 gives curves of the mass flux and the fraction of the current branched off to the discharge ($\delta I = 1 - 1/h_0$) versus electric field at $H_0 = 1$ MOe (the solid curves refer to calculations for a discharge sustained by electron thermal conduction with allowance for all significant effects, and the dashed curves refer to calculations for discharge sustained by radiation from the plasma). In the case of a discharge sustained by electron thermal conduction with the value of E corresponding to the limiting regime of insulator vaporization (and the maximum branching of the current) for $H_0 = 1$ MOe in the radiative problem, the branched current is 10 times lower and the mass flux is 15 times smaller. For the value of E corresponding to $\delta I \approx 10\%$ in the radiative problem, the branched current in the case considered is 3 times lower and the mass flux 4 times smaller. Thus, even for a discharge occurring on the surface, its deleterious effect is weaker in the case of no radiation incident on the insulator surface (for example, in the case of protection of the insulator against radiation).

Conclusions. The present study shows that emergence of a magnetic field through an insulator surface results in a stationary discharge regime if the discharge is sustained by electron thermal conductivity, taking into account all effects of significance, including plasma magnetization and the Nernst effect.

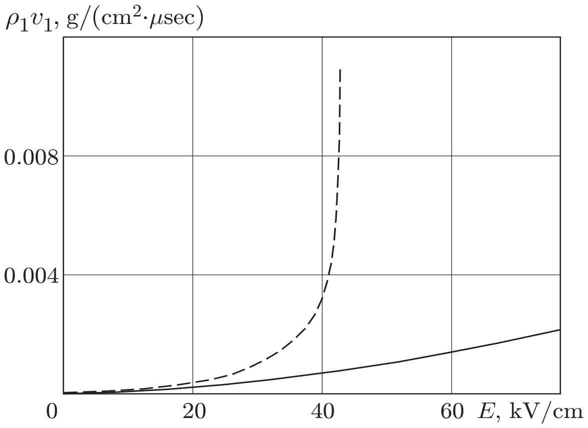

Fig. 5

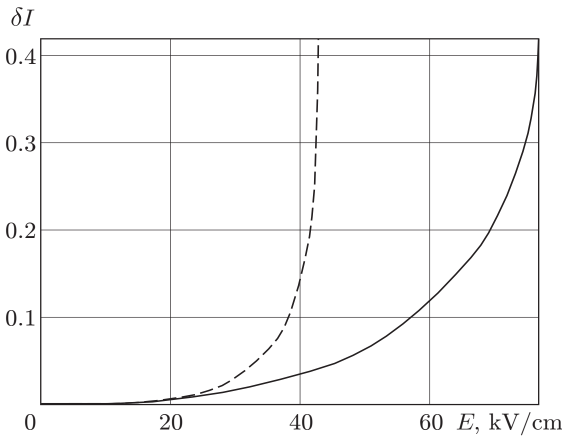

Fig. 6

Fig. 5. Mass flux at the exit from the discharge zone versus electric field.

Fig. 6. Fraction of the current branched off to the discharge versus electric field.

If the insulator surface is protected from radiation with preservation of the electric field magnitude (for example, with preservation of the liner acceleration velocity), an H-pushed discharge has a considerably smaller negative effect. Thus, the mass flux of the insulator material to the load volume decreases by a factor of up to 15 compared to a discharge sustained by radiation, and the branched current decreases by a factor of 10, depending on the vaporization regime (the higher the vaporization rate, the larger the difference).

The discharge characteristics obtained for the ceramic insulator can be specified as the boundary conditions in calculations for units in the absence of radiation and can be used to estimate the minimum discharge parameters in the case where the radiation flux is unknown.

We thank A. A. Karpikov and V. B. Yakubov for useful discussions.

REFERENCES

1. S. F. Garanin, E. S. Pavlovskii, and V. B. Yakubov, "Stationary discharge accompanying emergence of the magnetic flux through the surface of an insulator," *J. Appl. Mech. Tech. Phys.*, **2**, 171–176 (1984).
2. S. F. Garanin, V. A. Demidov, A. N. Demin, et al., "Study of ponderomotive systems on models," in: V. M. Titov and G. A. Shvetsov (eds.), *Megagauss Fields and Pulsed Power Systems*, Nova Science Publ., New York (1990), pp. 713–717.
3. S. I. Braginskii, "Transfer phenomena in plasmas," in: *Problems of Plasma Theory* (collected scientific papers) [in Russian], No. 1, Atomizdat, Moscow (1963).
4. Ya. B. Zel'dovich and Yu. P. Raizer, *Physics of Shock Waves and High-Temperature Hydrodynamic Phenomena* [in Russian], Nauka, Moscow (1966).
5. D. E. Post, R. V. Jensen, C. B. Tarter, et al., "Stationary-state radiative cooling rates for low-density high-temperature plasmas," in: *Atomic Data and Nuclear Data Tables*, Vol. 20 (1977), pp. 397–439.
6. G. A. Vergunova, S. F. Garanin, E. M. Ivanov, et al., "X-ray radiation of light impurities in a MAGO/MTF plasma," Preprint No. 43, Physical Institute, Russian Academy of Sciences, Moscow (2001).
7. E. M. Lifshitz and L. P. Pitaveskii, *Physical Kinetics* [in Russian], Nauka, Moscow (1979).
8. S. F. Garanin, "Physical principles of the MAGO system (magnetic compression)," Doct. Dissertation, Sarov (2000).
9. S. F. Garanin, "Diffusion of a strong magnetic field in a dense plasma," *J. Appl. Mech. Tech. Phys.*, No. 3, 308–312 (1985).