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USE OF ELECTRIC EXPLOSION OF WIRES IN A HIGH-PRESSURE GAS TO BREAK A CURRENT CIRCUIT

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The high energy densities stored in the magnetic field of inductive storage devices have promising applications in experimental physics. The greatest energy storage levels are achieved in superconducting storage facilities and pulsed facilities, operating with explosive-magnetic generators (currents up to $3 \cdot 10^8$ A) [1].

To use the energy stored in a magnetic field one must cut the current in the storage circuit and switch it to the load circuit. One method of doing this is to use a switch based on electrical explosion of wires (EEW) [1]. There are several difficulties in creating current cut-off devices of this type: After the electric explosion a column of metal vapor forms in which breakdown can occur; then the cut-off process is slowed and the energy-transfer efficiency is decreased. The problem is that the wire material is instantly vaporized, i.e., it is a dielectric subject to stresses arising when the inductive storage device is switched to the load.

As the pressure of the surrounding medium is increased it becomes more difficult to create shunting arcs in EEW devices and to produce conditions for more complete vaporization of the wire material. A series of tests has been conducted with different materials in order to elucidate the possible use of EEW in a high-pressure gas for current switching. The equipment contained a high-pressure chamber with inserted electrodes, between which a wire of the test material was attached. The chamber was filled with argon at a pressure in the range 1-750 atm. The wire diameter in the various tests was 0.5-1 mm. A control switch was used to discharge a condenser bank into the wire, of capacity 200 μF, voltage 3-6 kV, circuit inductance ∿ 1 μH, and with length of the first half-period current 50-100 μsec. The current and the voltage were measured using a shunt and a voltage divider, from which the signals were recorded on a type S1-29 oscilloscope. The results obtained are shown in Table 1, where l is the wire length; p is the inert gas pressure in the working chamber; I_{max} is the maximum current before explosion of the wire; I_{max}' is the maximum discharge current arising after EEW; $U_{c.b}$ is the voltage on the capacitor bank; and τ is the closure time, i.e., the time for the current to fall from its maximum value to zero. It can be seen from Table 1 that for a certain pressure (different value for the different metals) a closure effect occurs, i.e., after the current increases the EEW occurs and the electric circuit is broken. In this case part of the stored power remains in the capacitor bank. Of the metals tested, the most suitable for current interruption are Li and Al. At a pressure of more than 300 atm, wires of these

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TABLE 1

Wire material	Wire diameter, mm	l, cm	p, atm	I_{max}, kA	I'_{max}, kA	$U_{c.b}$, kV	τ, μsec
Al	0,5	6	10	9	7,5	3	
	0,5	6	100	9	4,5	3	
	0,5	6	200	9	2,8	3	
	0,5	6	300	9	0	3	10
	0,5	6	600	9	0	3	10
	0,5	6	600	14	13	5	
Li	1	6	100	9	5,5	3	
	1	6	300	9	0	3	20
	1	6	750	9	0	3	20
	1	6	750	13	5,5	5	
Ti	0,6	4	10	11	15	3	
	0,6	4	400	11	5	3	
	0,6	4	600	11	0	3	10
	0,6	4	600	23	31	6	
Cu	0,8	6	750	13	13	3	

metals gave efficient cut-off of currents of up to 10 kA at voltages ≈ 1.5–2 kV. For a Ti wire this pressure was greater than 600 atm. For copper, even at pressures of about 750 atm, the discharge did not extinguish and the current did not cut off for the same circuit values. The difference is evidently due to the thermodynamic properties (the fusion and boiling temperatures, the heat of sublimation, the critical parameters, etc.) of the elements, and this matter requires further study. We note that the critical pressure for Cu is much higher than for Li, Al, or Ti. In this work there was no difficulty in obtaining extremely high values of the cut-off currents and voltages. An increase in current can be obtained, in excess of the capacitor bank voltage, and this requires an increased length of the exploding wire.

To investigate the kinetics of vaporization of explosion products we used transverse x-ray illumination. We consider a technique for calculating the x-ray absorption signal in a radial density distribution. Since it is rather complicated to obtain the distribution analytically by the Abel method, the problem was solved numerically, assuming cylindrical similarity, as was done in [2] for symmetric sources. A projection of the test volume is shown in Fig. 1. A cylinder of the absorbing substance was divided into six angular zones of width a, in which the density was regarded as constant. The initial intensity of the x-ray radiation is I_{0k}, and the final intensity is I_k, where k is the number of bands of width a, extending through the cylinder of absorbing substance. The absorption of x-ray radiation is given by the law

$$I_k = I_{0k} e^{-\mu \rho_k d_k}, \tag{1}$$

where μ is the mass absorption coefficient; ρ_k is the material density; and d_k is the thickness of the absorbing layer. For an accurate solution we need to integrate Eq. (1), since d_k varies with the radius for each section of the absorber S_i. The problem can be simplified by considering that $d_i = S_i/a$, where S_i is the area of the absorption section. The areas S_i were determined by using the coefficients given in [2]. Thus, the intensity of x-ray radiation passing through the cylinder for the first band can be written in the form

$$I_1 = I_{01} e^{-\mu \rho_1 \frac{S_1}{a}} = I_{01} e^{-A \rho_1 S_1}, \tag{2}$$

where $A = \mu/a$ is a quantity which is constant for the given material and the chosen geometry.

For the second band

$$I_2 = I_{02} e^{-2A\rho_1 S_2} e^{-A\rho_2 S_3} \tag{3}$$

and so on for all six bands. By solving equations of types (2) and (3) for $\rho_1, \ldots, \rho_6$, we obtain

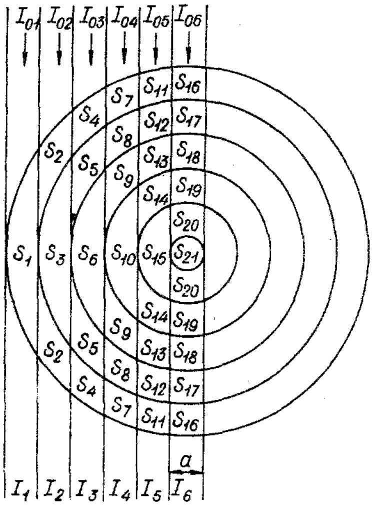

Fig. 1

$$\rho_1 = \frac{\ln \dfrac{I_1}{I_{01}}}{-AS_1}, \quad \rho_2 = \frac{\ln \dfrac{I_2}{I_{02}} + 2A\rho_1 S_2}{-AS_3}, \ldots .$$

The quantities I_k/I_{0k} were determined experimentally, by x-ray illumination. The quantities S_i were calculated by the method described in [2], and in computing A the parameter μ was taken as the handbook value of the mass absorption coefficient for x rays of wavelength λ_{eff}, corresponding to the effective wavelength for a beam from an x-ray tube with an anode voltage of 30 kV. This method was used to calculate the radial distribution of density for electrical explosion of an Ni wire in helium at pressure 10 atm. It was shown that at the moment of maximum discharge current the explosion products were expanded in the form of a hollow cylinder with a velocity ≈ 230 m/sec.

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