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# MAGNETIC COURSE GENERATORS USING THE TRANSITION OF A SEMICONDUCTOR MATERIAL INTO A CONDUCTING STATE

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UDC 538.4

At the present time there are a number of known explosion-type generators designed to obtain powerful pulses of an electric current and strong magnetic fields [1-6]. In these devices, the energy of an explosive is converted into electrical energy using conductors moving in a magnetic field. Thus, in MC (magnetic course) generators, the role of the moving conductors is played by the metallic parts of the electrical circuit, and, in MHD generators, by a high-velocity flow of conducting explosion products.

In [7], a method differing from the above is proposed for the formation of a moving conductor. For this purpose, a material having a semiconductor—metal-phase transition at reasonable pressures is used. With the passage of a shock wave over such a material, a conducting layer is formed behind its front. If the shock wave is propagated across the magnetic field, an inductive emf will be excited in the layer, which, with a closed configuration of the shock waves and the bounding conductors, can lead to the capture of the magnetic flux and its cumulation.

In the present article, experimental results from tests of generators working on silicon are given as well as some estimates of their parameters, made within the framework of an electrotechnical model.

1. Experiments were made in generators of flat and coaxial constructions. The working substance was brand KP-1 silicon, in the form of a powder with a grain size of 0.1-0.15 mm. The pressure of the phase transition of crystalline silicon was determined in [8] from static experiments and amounts to around 120 kbar; the conductivity of silicon in the metallic phase is close to the conductivity of the usual metals.

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Novosibirsk. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 5, pp. 125-129, September-October, 1980. Original article submitted March 28, 1980.

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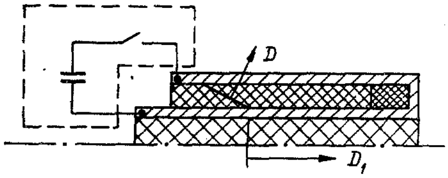


Fig. 1

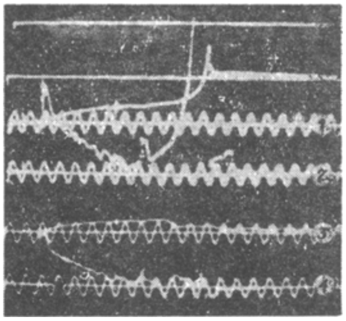

Fig. 2

The scheme of a coaxial generator is given in Fig. 1. The generator is made of copper tubes welded together at both ends. This part of the generator, with a length of 10 mm, serves as the load, where an induction pickup is installed for measurement of the current in the generator. The length of the working part of the generator is equal to 300 mm. The diameter of the outer tube is 30 mm, the thickness of the wall is 2 mm, the diameter of the inner tube is 18 mm, and the wall thickness is 1.5 mm. The space between the tubes is filled with silicon, which is densified by tamping. The charge of TG50/50 explosive is poured into the inner tube.

The initial current in the generator was set up by the discharge of a condenser battery. At the moment of a maximum of the initial current, the charge of explosive is ignited at a point opposite to the load. With the arrival of the shock wave at the silicon, a conducting layer is formed in the latter, which short-circuits the busbars of the generator and, moving toward the side of the load together with the detonation wave, constricts the magnetic flux.

Oscillograms of the current and the derivative of the current in the generator are shown in Fig. 2 (curves 1, 2). The initial current was 6.7 kA, and the final current 27 kA; the same figure shows oscillograms of a control experiment (curves 3, 4), in which the generator was filled with quartz powder. The absence of amplification of the current break-off in the first stage of the work of the generator bears witness that the presence of a powder between the busbars of a generator prevents their direct short-circuiting. The time markers on all the oscillograms represent 100 kHz.

The scheme of a generator of flat type is shown in Fig. 3. It consists of copper busbars 1 with a width of 15-20 mm and a thickness of 1 mm, between which there is a cassette 2 made of copper with a charge of explosive 3. The load of the generator is a one-turn solenoid 4 with an inside diameter of 8 mm, at which there is an inductive pickup for measurement of the current in the load. The distance between the busbars is 32 mm, and the thickness of the cassette with the charge of explosive TG50/50 is 12 mm. The length of the generators was varied in different experiments from 200 to 270 mm.

In these devices, the initial magnetic flux was set up either using an external electromagnet 5, with a time of rise in the current considerably longer than the working time of the generator, or by connection of the busbars directly to the condenser battery (not shown in Fig. 3).

An oscillogram of the derivative of the current in the load of such a generator, fed from a condenser battery, is shown in Fig. 4. The initial current in the generator was equal to 3.3 kA, and the final current was 0.1 kA. The time markers represent 100 kHz.

The oscillogram of the work of a flat generator in an external field is analogous to that shown. The initial magnetic field in the region where the generator was located was 3 kgf, and the current in the generator at the end of its work attained a value of 2.5 kA.

2. The equation describing the work of the generator in the case where the initial field is set up by the current flowing through its busbars has the form

$$\frac{d}{dt}(LI) + \left[R - \left(1 - \frac{u}{D}\right)\frac{dL}{dt}\right] I = 0 \tag{2.1}$$

and differs from the known equations for an MC circuit [9] by the presence of terms with the coefficient u/D, describing the convection of a field, frozen into the conductor formed with

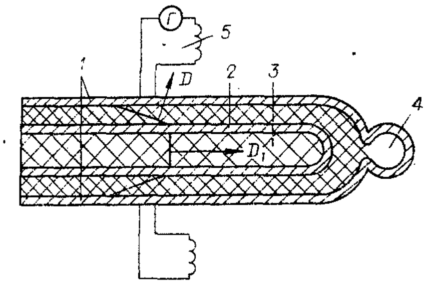


Fig. 3

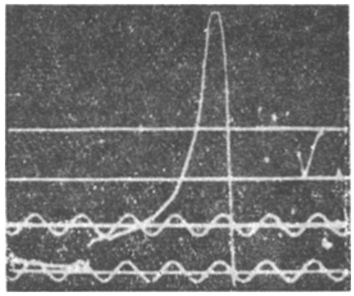

Fig. 4

a phase transition. Here D is the velocity of a shock wave in silicon; u, mass velocity behind the shock wave; R, resistance of the field of the generator.

In the experiments, the generators tested were not profiled; therefore, the rate of change in the inductance is constant. Then, the solution of Eq. (2.1) with the initial conditions $L(0) = L_0$, $I(0) = I_0$ will be

$$I = I_0\left(\frac{L_0}{L}\right)^{\frac{u}{D} - \frac{R}{|\dot{L}|}}. \tag{2.2}$$

The solution obtained conserves a power dependence of the amplification of the current on the tuning coefficient of the circuit $L_0/L$, as in classical MC generators. However, the power exponent is determined not only by the magnetic Reynolds number of the MC circuit $|\dot{L}|/R$, but by the ratio of the rate of convection u of a field with a moving conductor to the velocity of the shock wave D. It must be noted that the rate of change in the inductance of the generator $\dot{L}$ (the resistance of the generation) is determined by the rate $D_1$ of displacement of the boundary of the region of high pressure along the conductors of the generator. In the case of an inclined propagation of a shock wave in the substance, as is shown in Figs. 1 and 3, this velocity differs from the velocity D of the shock wave, and is connected with it by the relationship of $D_1 \sin\gamma = D$, where $\gamma$ is the angle of inclination of the shock wave to the direction of the propagation of the detonation wave in the charge of explosive.

With the work of a flat generator in an external field $B_0$, the equation of the circuit has the form

$$\frac{d}{dt}(LI) + \left[R - \left(1 - \frac{u}{D}\right)\frac{dL}{dt}\right] I = \frac{uaB_0}{\sin\gamma}, \tag{2.3}$$

where $a$ is the width of the channel of the generator. The solution of Eq. (2.3) with the initial conditions $L(0) = L_0$, $I(0) = 0$ will be

$$I = \frac{B_0 h}{\mu_0\left(1 - \frac{RD}{|\dot{L}|u}\right)}\left[\left(\frac{L_0}{L}\right)^{\frac{u}{D} - \frac{R}{|\dot{L}|}} - 1\right], \tag{2.4}$$

where h is the height of the channel of the generator.

From (2.2) it follows that the current in the generator will rise if

$$R < \frac{u}{D}|\dot{L}|. \tag{2.5}$$

This condition, with u = D, coincides with the condition obtained in [9] for the rise of the current in an MC circuit, while, with u < D, a more rigorous limitation is imposed on the permissible value of the active resistance of the circuit R.

For control of the form of a current pulse in [9] it is proposed to shape the busbar of the generator. Condition (2.5) shows that the form of a current pulse in a generator with a filler can be controlled within certain limits by changing the ratio u/D, which depends on the distribution of the charge of explosive along the length of the generator and the density of the packing of the filler.

Using (2.2) and neglecting the active resistance of the circuit, the energy in the generator can be represented in the form

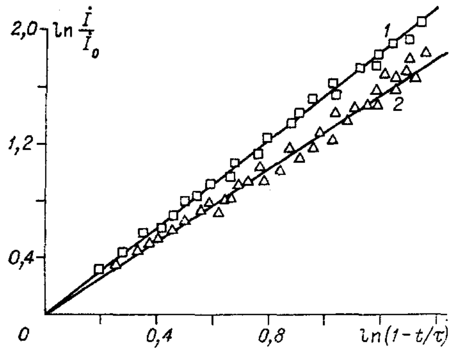


Fig. 5

$$\varepsilon = \varepsilon_0(L_0/L)^{2u/D-1}. \tag{2.6}$$

From this it follows that the energy stored in the generator will rise with the condition

$$2u > D. \tag{2.7}$$

Analogously, from (2.4) it follows that the energy connected with the initial magnetic field in the generator will rise during the course of its work, with satisfaction of the condition (2.7).

The above-noted special characteristics of the amplification of the current and the increase in the energy are specific for generators with a transition of the substance into a conducing state, and are connected with the convective removal of the flow from such generators, even with an ideal conductivity. To increase the efficiency of the generators in question, substances with a high compressibility must be selected, for which u approaches D to a high degree. This fact dictated the selection of powdered silicon in the above-described experiments.

3. From the oscillograms of the time derivative of the current, an estimate of the value of the resistance of the circuit of the tested generators can be obtained. Figure 5, in the coordinates $\ln(\dot{I}/\dot{I}_0) - \ln(1-t/\tau)$, where $\tau$ is the time of compression of the cavity of the generator, $\dot{I}_0$ is the initial discontinuity in the derivative of the current at the moment of closing of the circuit, illustrates the results of an analysis of three experiments with flat (points 1) and four experiments with coaxial (points 2) generators. For generators with constant values of R, $\dot{L}$, and u/D, from (2.2) and (2.4) it follows that the dependence of $\ln(\dot{I}/\dot{I}_0)$ on $\ln(1-t/\tau)$ should be represented by a straight line with a slope determined by the power exponent in (2.2), (2.3). The results of the experiments are in satisfactory agreement with this kind of dependence, which makes it possible to estimate the value of the active resistance of the conducting plug in the silicon and of the busbars of the generators. Under these circumstances, the value of u/D was measured in individual experiments by x-ray photography of the passage of a shock wave in the silicon powder, with arrangement of markers made of thin lead foil in the silicon powder. The values of the active resistance obtained for the experiments analyzed were found to be not greater than 0.1 mΩ. The low active resistance of the circuit shows that the resistance of silicon in a compressed state is close to the resistance of a metallic contact. However, the assertion that, in our experiments, the low resistance of silicon is explained by its transition to a metallic phase would be unfounded, since an effect of thermal excitation on the increase in the conductivity of powdered silicon with shock compression cannot be excluded.

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# MHD GENERATOR OF ELECTRICAL ENERGY WORKING ON THE GASIFICATION PRODUCTS OF LIGNITES

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UDC 538.4

One of the main trends in the development of present-day thermoelectric power engineering is its continuing reorientation toward the use of low-quality coals. At the same time, such coals are also being considered for the production of motor fuel. In our opinion, one promising means for the complex processing of coal with the simultaneous production of electrical energy and chemical products is the use of MHD converters of energy. The fundamental premises of this approach are set forth in [1]; therefore, the present article touches only on processes connected with the building of the MHD generator itself. The concept under consideration is based on the phenomenon of a T-layer (current layer) which was studied in [2-9]. A sufficiently clear understanding of the physical essence of this phenomenon makes it possible to approach with complete confidence the development of the theory of a generator as a gas-dynamic, heat, and electrical machine. A significant supplement to these considerations is provided by experimental investigations of an artifically initiated T-layer in a linear channel, the preliminary results of which are set forth in our present article.

1. Experimental Investigation of Models of MHD Generators with a T-Layer. Experiments on the artificial initiation of a T-layer were made in a unit having a rectangular MHD channel with solid electrodes. The cross section of the channel was 50 × 50 mm, the length of the electrode part was 200 mm, and the external magnetic field $B_0 \leqslant 1$ T. The flow of the working gas (helium with a hydrogen impurity) with the parameters $T \simeq 4000$°K, $p \simeq 1$ atm, and $u = 5$ km/sec was set up by an electric-discharge shock tube, and has steady-state parameters at the inlet to the MHD channel for a period of $10^{-4}$ sec. The temperature inhomogeneity, at which a T-layer is formed in the MHD channel, was set up at the inlet to the MHD channel by the discharge of a condenser battery. Figure 1 gives photographs of the consecutive phases of the motion of the T-layer in the MHD channel.

The experiments made demonstrated the possibility of obtaining a spatially stable structure of the T-layer and made it possible to determine its main parameters: the velocity, the conductivity, and the temperature. However, in view of the limitations inherent in this experimental unit, certain questions remained unclear: above all, the stability of the T-layer with its motion along the MHD channel, with a long interaction, and the conditions of the formation of a T-layer in the combustion products. The resolution of these questions made it necessary to build a qualitatively new unit, which would make it possible to carry out the above experiments and to compare them with calculated results. The parameters of the newly built pulsed unit were the following: working gas air or imitation combustion products; mass flow rate, 1 kg/sec; temperature ahead of nozzle, 2500°K; pressure ahead of nozzle 20 atm; duration of flow, $2 \cdot 10^{-3}$ sec; velocity of flow, 1.5 km/sec; cross section of MHD channel, 40 × 80 mm; length of electrode part, 2000 mm; induction of magnetic field, 2 T. The unit makes it possible to carry out the basic physical investigations needed to build an MHD generator working under periodic conditions. Simultaneously, work was started on the investigation of conditions for the periodic formation of a T-layer in a steady-state flow of gas.

Krasnoyarsk. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 5, pp. 129-138, September-October, 1980. Original article submitted March 10, 1980.

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