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STUDIES OF A MAGNETOCUMULATIVE SOURCE OF ELECTROMAGNETIC PULSES WITH A DOUBLE INDUCTIVE ENERGY STORAGE

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An energy source based on a helical magnetocumulative generator with simultaneous initiation of an explosive charge on the axis was developed. The generator operates on a double inductive energy storage with current circuit breakers in each storage. The main analytical dependences of the pulse amplitude and shape on the parameters of the double inductive energy storage were obtained. In an experiment with such an energy source, a voltage pulse of 770–800 kV *was obtained on a breaker made of electrically exploding wires. The voltage at possible load points was* 1300–1350 kV*. The duration of the voltage pulse edge from* $0.1U_{\max}$ *to* $0.9U_{\max}$ *did not exceed* 0.5 *μsec.*

Key words: *magnetocumulative generator, inductive storage, current circuit breaker.*

Magnetocumulative generators (MCGs) are powerful sources of magnetic energy pulses. The ranges of the duration and shape of the current pulses produced by MCGs are rather narrow and are determined by the detonation velocity of the most powerful explosives used in these devices.

Current pulses of various shapes and durations over a wide range of loads are produced using various circuit designs to match generator parameters to load parameters. For example, load current pulses of the required shape and duration with a power comparable to or higher than the MCG power are produced using inductive coupling of the generator circuit to the load circuit; storage of the magnetic energy generated by the MCG, and switching of the magnetic energy to the load by means of breakers made of electrically exploded wires (EEWs) or explosive current switches and plasma-erosion switches of various types.

When using breakers made of electrically exploded copper wires, the current source power amplification is low [1]. Therefore, to produce powerful energy pulses, it is necessary to use high-speed MCG. One of such devices is a helical generator with simultaneous axial initiation of an explosive charge — a helical AMCG [2]. This generator has a high power density in operating on a load with a rather high inductance [3].

At the Institute of Experimental Physics, experimental studies have been performed with a helical AMCG with an inside diameter of the helix of 115 mm and a working section length of 330 mm. The generator operated on a load consisting of an inductive storage and a current circuit breaker. In the experiments with this generator, a current pulse with a power of more than 90 GW was obtained on the EEW breaker. The breaker voltage was over 800 kV, and the voltage across the effective breaker resistance was over 900 kV.

Theoretical studies of an energy source based on a helical AMCG showed that voltage pulses over 1 MV can be produced on a breaker made of electrically exploded copper wires. However, because the generator output voltage is high, explosion of the EEWs deteriorates its electrical strength, thus decreasing the output parameters of the device.

To raise the electrical strength of the generator output, it is necessary to increase the thickness of the helix insulation. In addition, breakdown processes between the helix turns and the generator liner are also possible.

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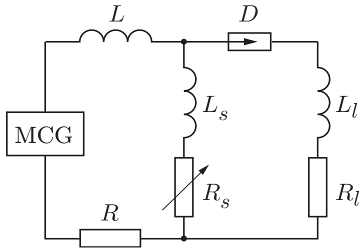

Fig. 1. Traditional pulse forming circuit.

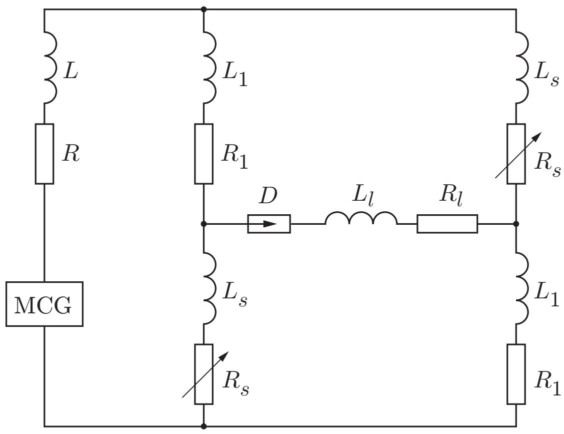

Fig. 2. Equivalent electrical circuit of an inductive energy storage.

Premature development of these processes can be prevented by placing an additional insulator under the helix turns. This increases the unwanted inductance and decreases the generator power. Therefore, in choosing insulation thickness, it is necessary to take into account both of the above-mentioned factors.

Further perfection of energy sources based on a helical AMCG can be achieved by using a double inductive storage circuit [4, 5]. This makes it possible to increase the maximum voltage at possible load points without an increase in the maximum generator output voltage with conservation of the maximum parameters at the current circuit breaker.

Inductive Energy Storage Circuit. A traditional circuit for forming current pulses of the required shape and duration is shown schematically in Fig. 1. The current source, in particular, an MCG produces current I_0 in a circuit with inductance $L+L_s$ and effective resistance $R+R_s$. At a certain time, the breaker resistance R_s increases abruptly to the maximum value. The voltage that has arisen across the breaker resistance leads to operation of the untriggered discharger D, as a result of which the energy accumulated in the inductive storage L is transferred to the load with parameters L_l and R_l.

When the edge of the load current pulse has a smaller duration than the total duration, the maximum power on the effective load resistance is attained for

$$R_l \approx R_s \frac{L+L_l}{L+L_s} + R \frac{L_s+L_l}{L+L_s}.$$

In this case, the maximum energy is determined from the expression

$$P_l = \frac{I_0^2 R_s}{4} \frac{(1-RL_s/(R_sL))^2}{(1+L_s/L)(1+L_l/L+(L_l+L_s)R/(LR_s))} \xi^2,$$

where

$$\xi = \exp\Big(\frac{\lambda-a}{2}t\Big) - \exp\Big(-\frac{\lambda+a}{2}t\Big), \qquad \lambda^2 = a^2 - 4b,$$

$$a = \frac{R_s}{L_s+LL_l/(L+L_l)} + \frac{R_l}{L_l+LL_s/(L+L_s)} + \frac{R}{L+L_sL_l/(L_s+L_l)},$$

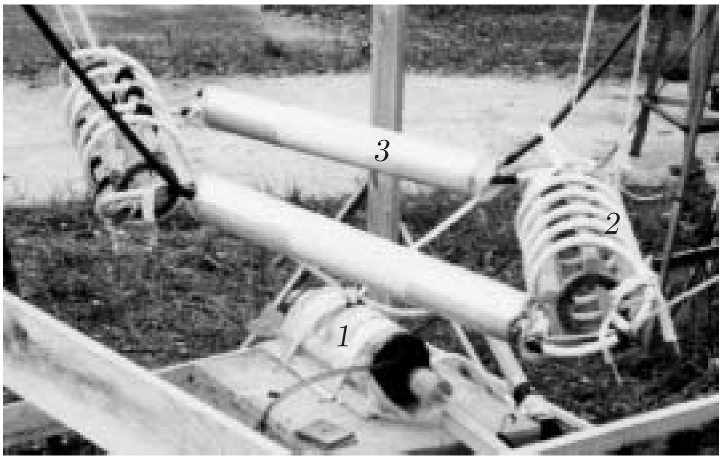

Fig. 3. Energy source before experiment: helical MCG (1), magnetic storage (2), and current circuit breaker (3).

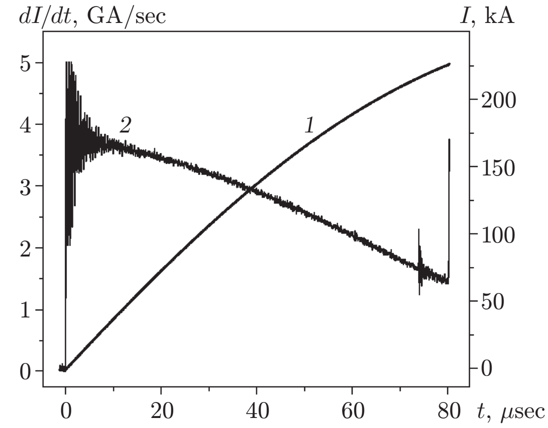

Fig. 4. Current (1) and current derivative (2) in the external solenoid circuit.

$$b = \frac{RR_l + RR_s + R_sR_l}{LL_l + LL_s + L_sL_l}.$$

The voltage across the effective load resistance for the maximum power takeoff is written as

$$U_l = \frac{I_0R_s}{2}\,\frac{1 - RL_s/(R_sL)}{1 + L_s/L}\,\xi.$$

In a traditional inductive storage circuit, the voltage across the effective load resistance for the maximum power takeoff cannot exceed half the breaker voltage at the moment of load switching and the maximum transferred power does not exceed 25% of the breaker power.

In [4], a double inductive storage circuit was proposed in which the maximum breaker voltage for the maximum power takeoff can be applied to the load resistance. An equivalent electrical circuit of the inductive energy storage is given in Fig. 2. The magnetic energy generated by a current source with inductance L and effective resistance R is accumulated in two parallel inductive storages. The inductance and effective resistance of each storage are L_1 and R_1, respectively. A current switch (breaker), whose effective resistance changes abruptly from zero to R_s, is connected in series to each inductive storage. The breaker inductance is L_s. At the time of attainment of the maximum breaker voltage, the peaking discharger D operates and a current pulse L_l arises on the load with inductance R_l and effective resistance I_l.

The maximum power on the effective load resistance is attained for

$$R_l \approx 2R_s\,\frac{L_1 + L_l}{L_1 + 2L_l + L_s} + R_1\,\frac{2L_s + L + L_l}{L_1 + 2L + L_s} + R\,\frac{L_1 + L_s + 2L_l}{L_1 + 2L + L_s}.$$

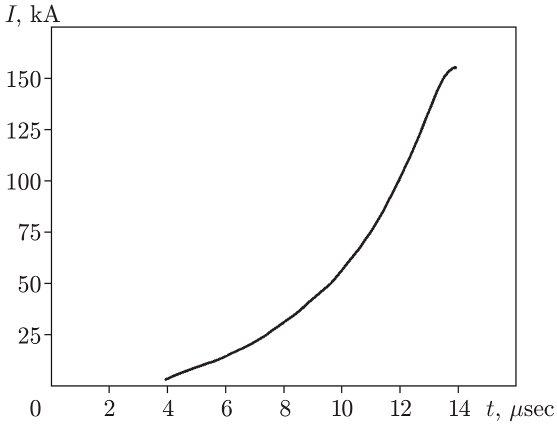

Fig. 5

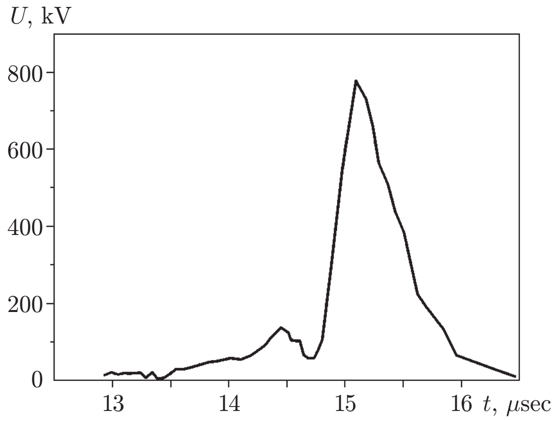

Fig. 6

Fig. 5. Generator circuit current.

Fig. 6. Oscillogram of voltage across one breaker module.

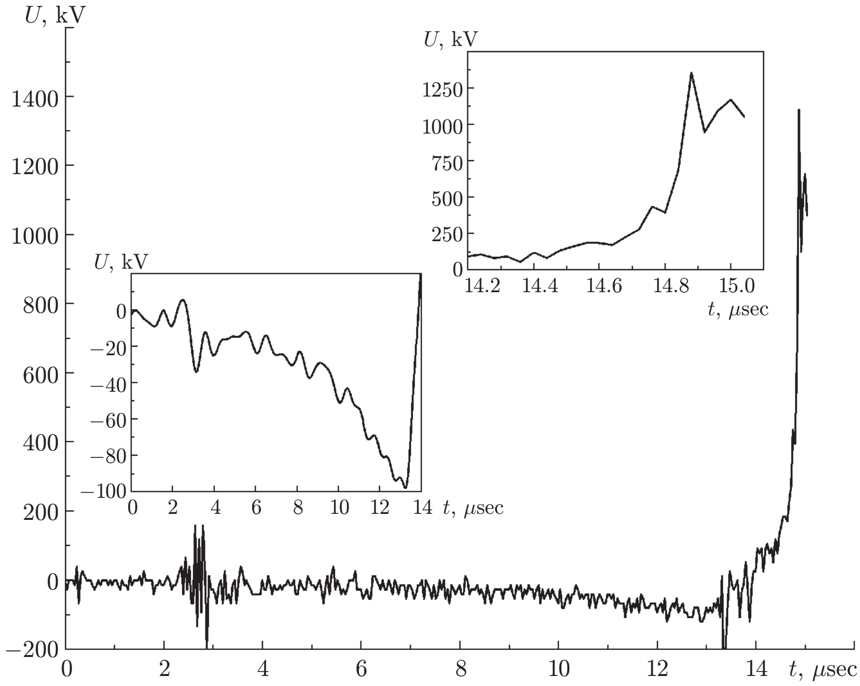

Fig. 7. Oscillogram of voltage at possible load points.

As in traditional inductive storages, the maximum power does not exceed 25% of the total power on the breakers. However, the load resistance voltage in this case can reach the maximum voltage across the breakers. For $R_l \gg 2R_s$, the load voltage pulse is almost twice the voltage across each of the breakers. Use of a double inductive storage increases the load voltage by a factor of almost two without a decease in the transferred power.

Results of Experiments. To confirm the possibility of designing a magnetocumulative source of electromagnetic pulses with a double inductive energy storage, we performed an experiment with a helical AMCG. The generator helix was 330 mm long, the inside radius of the helix over the insulation was 57.5 mm, the number of helix turns 24, the outside radius of the central tube 36 mm, and the outside radius of the cylindrical explosive charge, 32.5 mm. The initial generator inductance was approximately 15 μH.

The initial field inside the generator was produced by an external solenoid with flow interception. The parameters of the external solenoid were as follows: length 330 mm, mean radius 75 mm, and the number of turns 14. The solenoid inductance was approximately 8 μH.

The inductive storage consisted of two identical solenoids. Each solenoid had five turns. The mean diameter of the solenoids was 250 mm and the length was 725 mm. The inductance of one solenoid together with the leads was 4.7 μH.

The current circuit breaker consisted of two modules made of 50 copper wires with a diameter of 0.12 mm. The wires 1100 mm long were wound on two frames with a diameter of 110 mm at a length of 850 mm (25 wires in one module).

The inductance of one breaker module was estimated at 0.6 μH, and the inductance of the unit connecting the voltage pulse forming device to the MCG was 0.5 μH. The initial effective resistance of the copper wires of one module was 70 mΩ, and their mass was 2.75 g.

The appearance of the energy source before the experiment is shown in Fig. 3.

The initial field was produced by a 900 μF capacitor bank with a charging voltage of 35 kV, and the supply line inductance was 1 μH.

Figure 4 shows an oscillogram of the time derivative of the current and the current curve in the external solenoid circuit. Before the beginning of generator operation, the current value in the external solenoid was 225 kA. Thus, the power supply time was 80 μsec.

The generator circuit current curve obtained in the Experiment is presented in Fig. 5. The maximum value of the generator current is in the range 150–160 kA. Figure 6 shows an oscillogram of voltage across one breaker module, and Figure 7 gives an oscillogram of voltage at possible load points (see Fig. 2). The maximum voltage across one breaker module was 770–800 kV, and the voltage at possible load points was 1300–1350 kV with an edge of less than 0.5 μsec from the value of $0.1U_{\max}$ to the value of $0.9U_{\max}$.

The experimental results agree well with the calculations performed. Thus, the possibility of forming powerful energy pulses in the megavolt voltage range using a double inductive generator with an inductive energy storage was supported experimentally.

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