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TRANSPORTABLE SIMULATORS OF ELECTROMAGNETIC PULSES BASED ON MAGNETOCUMULATIVE GENERATORS

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Transportable simulators of electromagnetic pulses that can be delivered directly to the locations of tested objects are designed for tests of the resistance of various wide-scale objects to the action of electromagnetic pulses. Explosive magnetocumulative generators are used as the power sources. The tested objects are protected from the effects of explosion of the generators by simple protective facilities. Experiments on the production of pulsed magnetic fields in volumes of up to 100 m^3 *were performed. A current-pulse shaping scheme was used to generate a rapidly increasing field. Plane electromagnetic waves were produced by means of an air-strip line powered from the generators. The action of electromagnetic pulses on buried cable lines was modeled. Test specimens of simulators of the action of electromagnetic pulses and lightning current are produced.*

Because of the complexity of the radio-electronic equipment in current use in communication, check, and control systems of various objects, there is a danger of failure or malfunction of operation of this equipment due to the action of electromagnetic pulses (EMP) [1]. Reliable data on the resistance of equipment to the action of pulsed electric and magnetic fields can be obtained only by combination of computational and experimental methods [2]. In this case, the results of tests validate the requirements imposed on the resistance of the equipment.

Work on the design of transportable installations for testing the action of EMP (simulators of EMP) was begun at the Institute of Experimental Physics under the initiative and direction of Academician A. I. Pavlovskii in the late 1970s. As the power source, a magnetocumulative generator (MCG) was used in which conversion of the energy of an explosive to electromagnetic energy was performed under rapid deformation by explosion of the current-carrying circuit. The use of an MCG as a powerful energy source for transportable EMP simulators is motivated by its high energy characteristics in conjunction with the wide variability of the energy and the time of energy input into the load, its ransportability and independence, simple service, the possibility of storage and use under field conditions, and low cost.

For solution of a number of scientific and technological problems, a broad class of MCG was designed which generate energy of up to 100–1000 MJ with various times of energy input into the load [3]. The production models of magnetocumulative generators have the following characteristics: MKG-80 generates an energy of about 200 kJ in a load with an inductance of approximately 6 μH at an initial energy of 1–2 kJ; MKG-160 generates an energy of approximately 2 MJ in a load with an inductance of about 15 μH; MKG-320 generates an energy of 10–15 MJ in a load with an inductance of 0.1–1.0 μH. The indicated generators can be used to design a cascade system.

Using magnetocumulative generators, it is possible to design systems (similar to capacitor banks)

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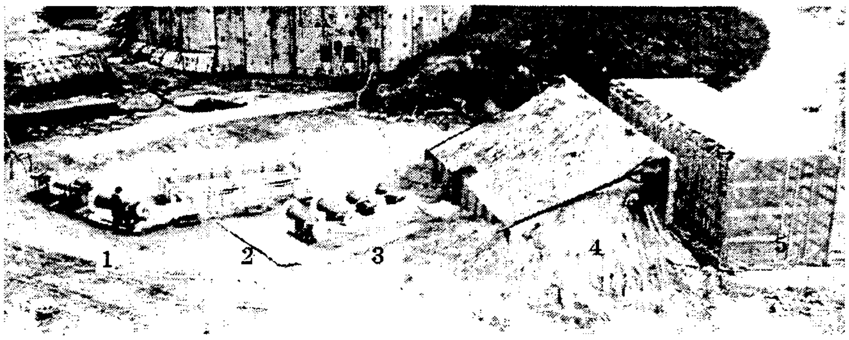

Fig. 1. Facility for producing magnetic fields in large volumes: 1) cascade of MKG-80, MKG-160, and MKG-320 generators; 2) matching transformer; 3) MC battery; 4) protection; 5) solenoid.

consisting of a large number of MCG that simultaneously operate on a unified load (MC battery) [3]. As a result, high energy and power are generated, and the energy delivered to the load can be varied by changing the number of generators in the MC battery.

The large energy capacity of MCG-based sources allows one to produce high pulsed magnetic fields with a strength of up to 1 MA/m in volumes of about 100 m^3 and, hence, to study the action of these fields on the equipment of large-scale objects [4].

MCG are convenient for producing magnetic fields with a rise time equal to the rise time of the generator current (10–100 μsec). The generation of such magnetic fields is of interest, for example, in testing the equipment of objects protected by thick solid conducting screens for their resistance to the action of a rapidly increasing pulsed magnetic field, where the pulse shape on the internal surface of the screen does not depend on the rise time of the field on the external surface. Therefore, if the rise time of the current pulse from the power source is much shorter than its decay time, it is not necessary to use subsidary switches to shape shorter fronts. Attaining the required spectral characteristics of the pulse and the rate of rise in the field inside the screen by increasing the amplitude, it is possible to estimate the operating capacity of the tested equipment under the rapidly increasing EMP.

A series of experiments on generation of high pulsed magnetic fields in large volumes was performed. In the experiments, MCG of various types were used as the power source. In one of the experiments, the problem of producing a pulsed magnetic field with a strength of 1 MA/m in a volume of 200 m^3 was solved. The general view of the facility for producing such magnetic fields is shown in Fig. 1. An MCG battery consisting of four production MKG-320 was used as the power source. A pulsed magnetic field was generated in a single-turn solenoid made from 50 wires of the BPVL-70 type wound in parallel on a wood framework of square cross section with dimensions $4 \times 4 \times 12$ m. The inductance of the solenoid was 1.6 μH. The solenoid was protected against the explosion of the MCG by a ground bank.

The magnetic field produced in the solenoid has a maximum strength of 0.5 MA/m. During almost the entire operation time of the MC battery, the rate of rise in the magnetic strength was constant in time [4 GA/(m $\cdot$ sec)]. The rise time of the magnetic-field pulse was 100 μsec, and the characteristic decay time was 10 msec. The magnetic energy in the working volume of the solenoid was approximately 35 MJ, and the magnetic energy generated by the MC-battery was 55 MJ. In this experiment, the problem of forming a shorter rise front of the pulsed magnetic field was not posed, and the rise time of the field was determined by the operation time of a single generator of the MC battery. However, in this case too, the spectral characteristics of the magnetic-field pulse greatly surpassed the stated requirements on the resistance to the action of a pulsed magnetic field due to a lightning discharge. We note that tests of equipment under the action of high pulsed electromagnetic fields with peak and spectral characteristics superior to those prescribed makes it possible to obtain more reliable data on the resistance of the equipment, to reduce the number of tests, and to refine the standards and methods of testing.

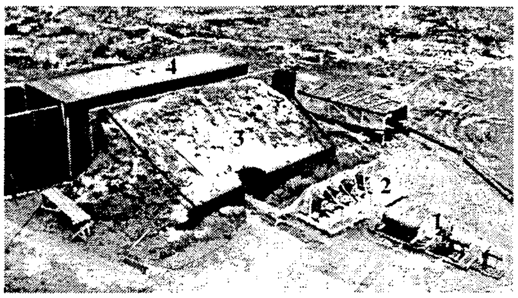

Fig. 2. Facility for producing a magnetic-field pulse with a short leading edge: 1) cascade of MKG-80, MKG-160, and MKG-320 generators; 2) MC battery of short helical generators; 3) protection; 4) solenoid.

Helical MCG with axial initiation are characterized by a shorter current rise time [3]. A magnetic field with a strength of 0.1 MA/m, a rise time of 10 μsec, and a decay time of about 1 msec was produced experimentally in a volume of 100 m^3 using an MCG battery of short helical generators with axial initiation powered by an MKG-320 (Fig. 2). The maximum rate of field pulse rise was 10 GA/m · sec.

A further decrease in the magnetic-field pulse rise duration was ensured by using the conventional electrotechnical methods of pulse sharpening. In an experiment using an MKG-80 generator with a shaping device consisting of electrically exploding wires and a sharpening discharger, a magnetic field with a strength of 10 kA/m, a rise time of 2 μsec, and a decay time of about 1 msec was produced in a solenoid with a volume of 100 m^3. The maximum rate of increase in the magnetic-field strengths in the solenoid was 10 GA/(m·sec).

A series of experiments on generation of plane electromagnetic waves by means of MCG was also performed [4]. An air-strip line 5 m high, 20 m wide, and 60 m long was used. The upper sheet of the air-strip line consisted of 19 split brass wires of 3 mm diameter distributed uniformly along rings with diameters of 500 mm (outer split wires) and 250 mm (middle wires). The lower sheet was a solid metal mesh with cell sizes of 200 × 200 mm made from a steel bar 8–10 mm in diameter. At the beginning and end of the air-strip line there were transition sections served to connect it to the electromagnetic-field generating system and to the active resistance at the end of the line equal to the wave drag of the line.

The current-pulse shaping system consisted of an MKG-80 energy source, energy storage circuits, a mesh of exploding conductors, and a sharpening unit. The storage circuit was a solenoid made from a high-voltage wire, whose inductance together with the leads was 5 μH. The mesh (5.0 × 1.3 m) of exploding conductors was made from 25 wires of the MGTF-0.07 type that were 1.3 m long and distributed uniformly. The sharpening unit comprised six controlled gas-filled dischargers that were placed uniformly in a region 5 m long and connected in parallel to the circuit.

Use of several dischargers connected in parallel made it possible, apart from decreasing the inductance of the rupture unit, and, hence, the time of current transfer into the strip-line, to supply voltage at different points of the lowering strip and to generate in the air-strip line an electromagnetic wave that is similar in spatial structure to a plane electromagnetic wave. In the experiments performed, the magnetic energy generated in the storage circuit was about 100 kJ, the voltage across the mesh of electrically exploding conductors was approximately 500 kV, and the current strength in the strip line was about 6 kA. The field pulse rise time in the wave was 20–40 nsec, and the decay time was about 1 μsec.

More powerful MCG will make it possible to considerably increase the strip-line dimensions and the voltage across the mesh of exploding wires. The main difficulty is associated with the design of controlled dischargers of the megavolt range.

It is known that under the action of the electrical component of EMP produced by a nuclear explosion, currents with an amplitude of about 100 kA are induced in the screens of buried cable lines [5]. These currents can be transferred along the screens inside the protected facilities and can induce currents in the internal elements of the cable lines. MCG-based energy sources can be used to induce currents with required

Fig. 3. Experimental facility for inducing currents in the cable screen by the induction method (MCG are located inside a spherical explosive chamber).

amplitude-time characteristics in the cable screen. Figure 3 gives a general view of a facility for inducing currents in the screen of a cable 30 m long by a noncontact (induction) method. The energy sources were MKG-80 and MKG-160 generators with shaping devices in the form of a mesh of electrically exploding conductors and sharpening dischargers. The magnetocumulative generators were placed in an explosive chamber. The connection loop used for induction connection of the MCG to the cable consisted of two KVI-300-type wires with strengthened insulation, between which there was the examined cable. The current induced in the cable screen by the MKG-80 generator had an amplitude of about 30 kA, a rise time of 5 μsec, and a duration of 100 μsec; the current produced by the MKG-160 generator had an amplitude of 100 kA, a rise time of 2 μsec, and a duration of 1 msec.

A contact method of inducing currents in the screen of a cable about 100 m long was also tested. In this case, the screen of the cable was connected by means of a special coupling to the output terminals of the energy source. The MKG-80 generator produced a current with an amplitude of up to 200 kA, a rise time of approximately 100 μsec, and a decay time of about 1 msec; the MKG-160 generator increases the amplitude to 300 kA with a rise time of 200 μsec, and a decay time of approximately 2 msec. The generators were placed in simple protective facilities to protect the recording instrumentation and the surrounding facilities from the damaging factors of the MCG explosion. Figure 4a shows four protective facilities before the experiment. The MCG is placed in the extreme right facility. In the MCG explosion, the facility adjacent to the MCG remains intact and is used in a second experiment, etc. Preparation of the experiment is shown in Fig. 4b.

Many research problems of the resistance of equipment to the action of lightning EMP can also be solved using MCG. The action of lightning current can lead to considerable mechanical damage, fire, disturbance of functional connections between particular units of equipment, induction of a current, and the occurrence of pulsed overstresses in cable lines and wires. Usually, it is required to confirm the resistance of objects or equipment to the action of lightning directly at places of their location and operation with all connections and grounds. Tests of such objects require a transportable simulator of the lightning effect.

Test specimens of transportable simulators of the effect of pulsed current of lightning were designed [6, 7]. They incorporate an energy source based on MKG-80 or MKG-160, shaping devices based on electrically exploding conductors and a sharpening discharger, and a line connecting the high-voltage terminal of the exploding wires through the sharpening discharger to the loaded object; the inverse current lead is usually ground (the simulator is loaded on the real ground resistance of the tested object).

Two types of shaping devices are used: a storage circuit with an exploding conductor or several identical storage circuits connected in parallel to the MCG output (Fig. 5). In an experiment with the first type of simulator, where the ground resistance was 4 Ω and the length of the line connecting the simulator to the loaded object was equal to 60 m, the effect of a lightning current with an amplitude of 50 kA was simulated. The current rise time was 7 μsec, and the decay time at the pulse half-height was 65 μsec. In this case, the voltage pulse supplied to the tested object had an amplitude of about 1 MV. In an experiment using two

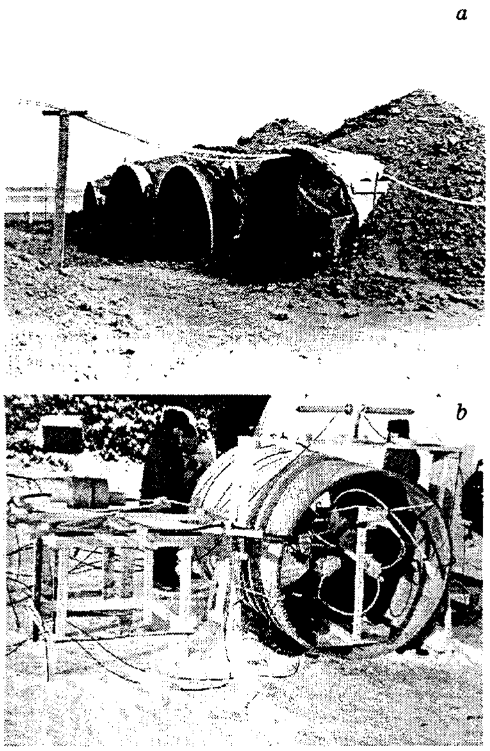

Fig. 4

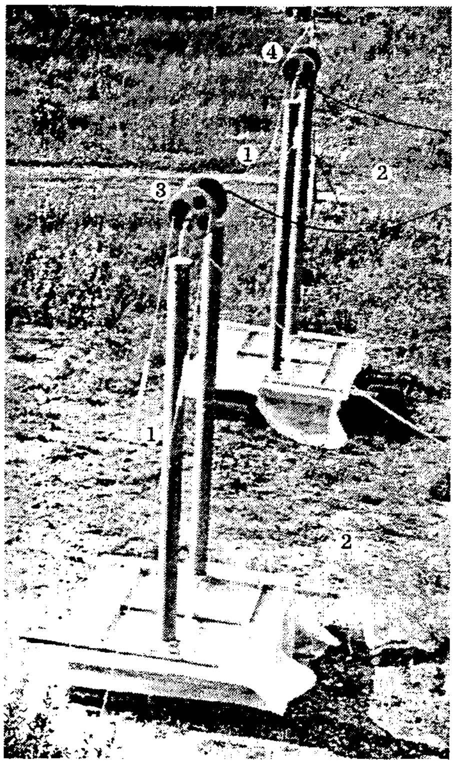

Fig. 5

Fig. 4. Four protective facilities: (a) before the experiment; (b) preparation of the experiment.

Fig. 5. Fragment of a shaping device consisting of several storage circuits with exploding conductors: 1) exploding conductors; 2) storage circuits; 3) discharger; 4) sharpening discharger.

storage circuits (second type of simulator) a current pulse of the same amplitude was produced at a ground resistance of 27 Ω. The voltage across the tested object was 2 MV, the current rise time was 3 μsec, and the decay time (at half-height) was 30 μsec.

A method for generating a pulsed magnetic field in ground using a magnetic dipole powered by an MKG-160 generator was proposed. The possibility of producing a magnetic dipole with a moment of up to 1 GA $\cdot$ m^2 is shown. For a 50-m-diameter turn divided into four sections, a production MKG-160 generator produces a magnetic moment of up to 0.25 GA $\cdot$ m^2. Sharpeners can be used, for example, exploding conductors, depending on the required rise time of the dipole current.

The experiments performed at the Institute of Experimental Physics showed that MCG hold promise for the design of transportable simulators of EMP.

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