EXPLOSIVE SWITCHING OF AN ELECTRIC CURRENT

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UDC 621.316.5

Experiments are described involving a circuit-breaker element capable of switching a current with a line density of up to $3 \cdot 10^5$ A/cm in a time of 5 μsec. A suggested application for this device is explosive-magnetic generators with tuned bank inductance.

1. The energy density stored in the magntic field of inductor banks produced in recent years is several orders of magnitude larger than the energy density of capacitor banks, and this holds out promise for using inductor banks in experimental physics. The largest energy storage levels have been attained in steady-state superconducting banks [1], and in pulsed banks, fed from explosive-magnetic generators (EMG's), operating on the principle of fast compression of magnetic flux [2, 3]. In the latter case the bank has a small inductance (1 to 20 nH), but the current reaches enormous values (up to $3 \cdot 10^8$ A).

The energy stored in a magnetic field can be utilized by means of a circuit-breaker in the bank circuit and a switch in the load circuit. For this purpose one uses switches based on electrical explosion of fine wires [4] or on mechanical disintegration of large conductors by means of explosive switches [5-7]. Here the efficiency of transmission of energy to the load depends on the active load resistance and on the ratio of the bank and load inductances. Low-inductance banks can operate well only with low-inductance loads, but switching of large currents into a load with an appreciable active impedance produces very large voltages. These features of energy transfer from an inductive bank make it difficult to use explosive-magnetic generators as a current source for quite a number of experiments.

To reduce the current transmitted to the load and to increase the bank inductance, an EMG scheme with a tuned bank inductance [8] has been suggested and experimentally verified. In this scheme the bank is initially a group of N coils connected in parallel, which are then switched to be in series. The initial bank inductance is low, and the bank operates efficiently with the EMG as an energy-storage device. After the coils are switched the bank current decreases by a factor of N, while its inductance increases by a factor of N^2. This arrangement allows one to match the bank with practically any load by adjusting the inductance.

The aim of the present paper is to develop and experimentally determine the operating time and the maximum line current density that can be interrupted by an individual switch element, with reference to a two-dimensional explosive magnetic generator with a tuned bank inductance. Since two-dimensional EMG's operate satisfactorily at a current of $I \approx 5 \cdot 10^5$ A/cm, it is necessary that each switch element should interrupt a current of this order. If this were not so the switch would be too bulky and difficult to control because of the large number of parallel-connected elements.

2. The particular layout features of the plane EMG'S (Fig. 1) determine the location of the switch. The circuit-breaker element consisted of segments of a metal ring (1) of height 12 mm, wall thickness 5 mm, and internal diameter 80 mm, attached on one side to the current buses (2), and on the other side to a bank coil (3). The walls of the ring had cutouts (4) of width 5 mm and depth 4 mm to promote accelerated rupture of the ring at these points. Inside the ring there was an explosive switch charge (5) of thickness 5 mm. There was provision in the experiments, in the event of damage to the charge, for shunting of the current source before the current would be broken by the explosion of the ring walls.

Novosibirsk. Translated from Zhurnal Prikladnaya Mekhanika i Tekhnicheskoi Fiziki, No. 1, pp. 66-68, January-February, 1975. Original article submitted June 14, 1974.

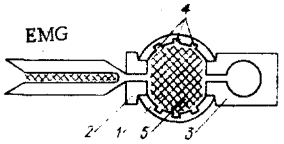

Fig. 1

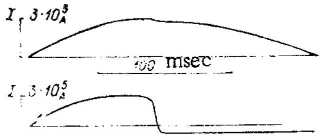

Fig. 2

It is clear from Fig. 1 that the circuit-breaker element should have a minimum inductance L_1, since the energy U_1 stored in it,

$$U_1 = U_0 \frac{L_1}{L_1 + L_2},$$

is certainly lost when the current is broken and cannot be used subsequently. Here U_0 is the initial energy transmitted by the source to the switch and to the bank with inductance L_2. In order to reduce the inductance of the breaker element in these experiments we used lateral metal patches to draw the magnetic field away from part of the ring volume.

The experimental arrangement corresponded to that shown in Fig. 1, with the difference that a capacitor bank with $C \approx 10^{-2}$ F and voltage up to 5 kV was used to obtain large pulse currents, instead of an explosive-magnetic generator. The capacitor bank discharged into the circuit-breaker, which was connected to a coil of the inductor bank. The explosive switch fired at the moment of maximum circuit current, shunting the discharge circuit of the capacitor bank and then interrupting the current in the inductor bank coil.

In the experiments the current was measured in the capacitor bank circuit and in the inductor bank coil. The signals from two inductive sensors, located in a coil of the solenoid and in front of the circuit-breaker, were supplied via integrating RC networks to the amplifiers of a type OK-17M oscilloscope. Oscillograms from one test are shown in Fig. 2. The upper trace shows the current in the capacitor bank circuit, and the lower trace shows the current in a coil of the inductor bank. The measurements made establish that reliable shunting of the source current was accomplished and that there was no effect on subsequent processes in the capacitor bank circuit. Agreement was observed (within the accuracy of measurement) in the capacitor bank discharge times with the circuit shunted by the circuit-breaker and without shunting.

The results of the experiments showed that there was uncontrolled breaking of the current at a certain time near the moment of maximum current, when the circuit current was $I \approx 4 \cdot 10^5$ A. The time for current interruption was 18 to 25 μsec. A possible cause for this is that the magnetic pressure ($B \approx 3 \cdot 10^5$ G, $P = B^2/8\pi \approx 4 \cdot 10^3$ atm) causes breakdown of one of the cutouts and excites an electric arc which may produce combustion and detonation of the explosive switch prior to firing of the detonator. Detonation of the explosive switch is accompanied by high-speed scattering of the explosion products which may blow away the arc and interrupt the current [6].

When the current was reduced to $I \approx 10^5$ A the circuit began to break at the proper time and occurred in 5 μsec. An increase in current by a factor of two increased the circuit-break time to 50 μsec. The start of operation of the circuit-breaker coincided with the detonator firing the explosive switch. Since interruption of high-level currents in inductive circuits produces large voltages, an increase in circuit-break time is naturally associated with possible breakdown and the appearance of electrical arcs at the points of rupture of the ring.

For subsequent experiments the circuit-breaker was improved. Copper plates of thickness 3 mm were attached on the outside, opposite to the cutouts in the ring, to inhibit breakdown of the circuit due to magnetic pressure. If breakdown of the ring produces an inert medium with high electrical strength, one can avoid the formation of concentrated arcs, which are an obstacle to rapid interruption of the current. With this goal an auxiliary explosive charge was fired before the scattered elements arrived at the postulated points of ring disintegration, and this created an atmosphere of explosion products with a low electrical conductivity. With this experimental arrangement currents of $I \approx 3 \cdot 10^5$ A could be interrupted in a time of 5 μsec.

Since the parameters determined for the circuit-breaker elements are close to the optimum operating conditions of two-dimensional explosive magnetic generators, it is evident that this design can be followed to produce explosive magnetic generators with a tuned inductor bank, and one can substantially improve the possible uses of explosive generators.

The authors thank P. I. Zubkov for valuable discussion and advice.

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