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USE OF MAGNETOCUMULATIVE GENERATORS IN EXPERIMENTS ON CURRENT DISRUPTION OF SHAPED-CHARGE JETS

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Results of experiments on disruption of shaped-charge jets by a pulsed current are reported. An industrially produced helical-coaxial magnetocumulative K-80 generator with transformer energy output was used as a source of energy. The operation of the generator in the experiments performed and the effect of the current-pulse parameters on jet disruption and depth of penetration of a shaped-charge jet into a target are discussed.

Introduction. Recently, the process of disruption of metallic shaped-charge jets (SCJ) by an electric current passing through them have been extensively studied both experimentally and theoretically [1–8]. The studies are performed in two directions. In one direction, the SCJ behavior is studied in the high-current regime, and the main goal is to determine the conditions of maximum possible jet disruption and to attain complete disruption. In the other direction, SCJ are investigated in the moderate-current regime. The main goal in this case is to attain partial disruption of SCJ at the least possible energy of the current source, and some jet penetration into the protected target is allowed. In this line of investigation there is a wide spread of the current-source energy required for a specified decrease in the depth of jet penetration into the target. This is due to the fact that development of natural hydrodynamic instability of a jet eventually leads to breakup of the jet into separate fragments. If a SCJ is connected to a current source at time Δt before the moment of jet breakup, indefiniteness arises in the treatment of the effectiveness of the electric energy ΔE imparted to the jet during passage of the electric current. For a small value of Δt, the energy ΔE can be very low but, nevertheless, the jet is disrupted. It is obvious that experimental results should be compared using a uniform approach to the experimental conditions and experimental facility design.

Since in high-current experiments, magnetocumulative generators (MCG) compete with capacitor banks, it is of interest to study the possibility of using them in experiments with SCJ because the explosive character of experiments with MCG is combined with explosion of a shaped charge. The advantages of MCG are their small dimensions and the possibility of producing high energy and current in them. This allows one to use generators with shaped charges of large and small diameters and to investigate SCJ disruption in both of the above-mentioned regimes.

However, there are two significant differences between a MCG and a capacitor bank. In a capacitor bank, electric energy has already been accumulated before closure of the electrodes by a jet, whereas for a MCG, a certain time is required to convert the HE energy into electric energy. Therefore, a mechanism of synchronizing the operation of the shaped charge and the MCG is needed. In addition, since at the same current amplitude, the action integral is as a rule much larger for capacitor-bank discharge than for MCG operation, sharpening of the MCG current pulse is required.

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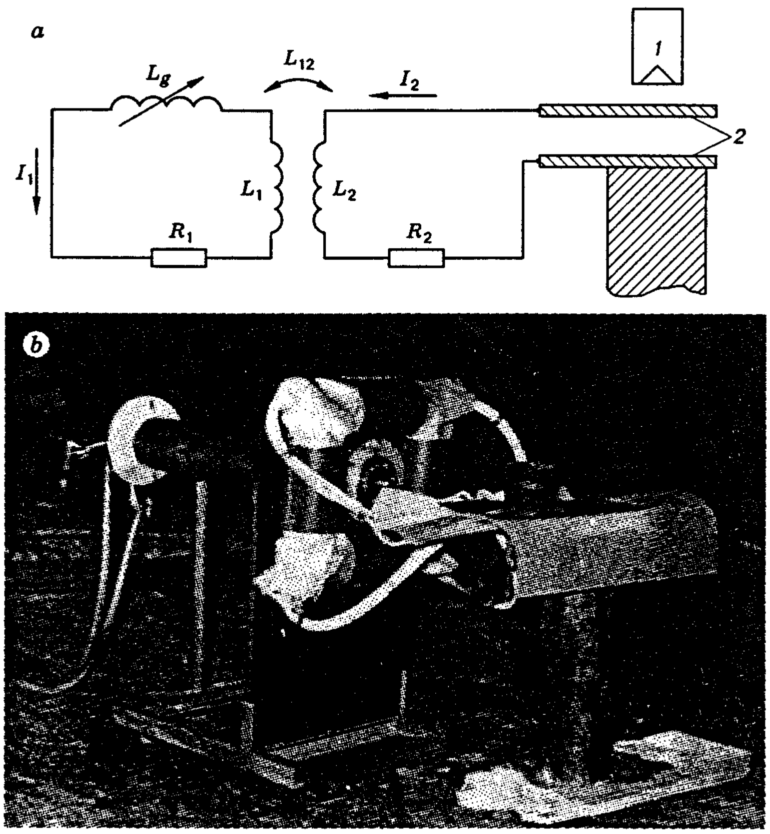

Fig. 1

For experiments with a SCJ, it is possible to use various types of MCG and various diagrams of connection of SCJ to MCG circuits. A SCJ can be switched to an MCG circuit both in the course of and after termination of MCG operation. In the latter case, the MCG operates in the charging regime of a certain intermediate inductive storage which is then switched to the jet. However, matching the parameters of the generator, intermediate loads, and SCJ is a rather complicated problem. It is possible that the use of MCG with external excitation [9] or transformer energy output is preferred [10–12].

The present paper reports results of experiments with transformer energy output MCG. The goal of these experiments is to show the fundamental possibility of using MCG of this type in experiments with SCJ and to elucidate features of such application. The experiments were performed with shaped charges of diameters 55 and 100 mm.

Diagram of the Experiments. A diagram of the experiments is shown in Fig. 1a, where 1 is the shaped charge and 2 are the contact plates (electrodes) connected to the secondary winding of a transformer. The remaining notation is standard. The experiments were performed with a modified K-80 generator. A photograph of the generator before the experiment is shown in Fig. 1b (the shaped charge is not shown).

The characteristics of K-80 generators are given in [10] (initial energy 2.0 kJ and load energy 250 kJ). In contrast to K-80 generators, for which the ratio of the helix-to-pipe diameters is 2, for the modified generator, this ratio is 2.5 because of the decrease in the diameter of the central pipe. As a result, the limiting value of the final current decreases from ~14–15 to ~12 MA, and the load energy is about 200 kJ. K-80 generators incorporate cable transformers, whereas the generator described uses a block of cylindrical wire transformers with a secondary-winding solenoid located inside primary winding. This decreases the coupling coefficient of the transformer from 0.94 to 0.92 but makes the transformer more compact.

At the beginning of generator operation (Fig. 1a), the secondary circuit is open and the generator operates at no load [12]. In this case, the closer the moment the jet completes the secondary circuit is to the

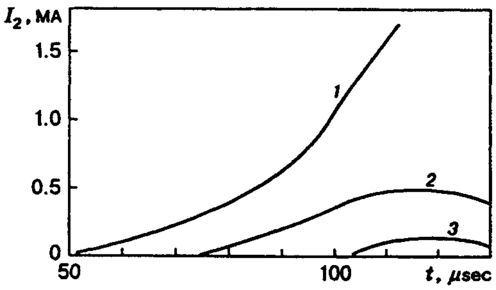

Fig. 2

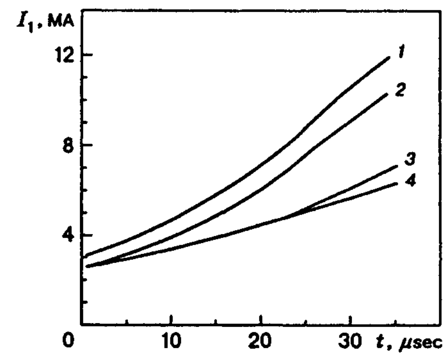

Fig. 3

TABLE 1

Experiment number	d, mm	t^*, μsec	I_{max}, kA	h, cm	h_0/h
1	55	36	600	5.5	3.5
2	55	8	200	5.5	3.5
3	100	13	290	31	1.5
4	100	16	350	25	1.9
5	100	26	430	27	1.7

Note. d **is the shaped-charge diameter and** h **is the penetration depth in experiments with a current.**

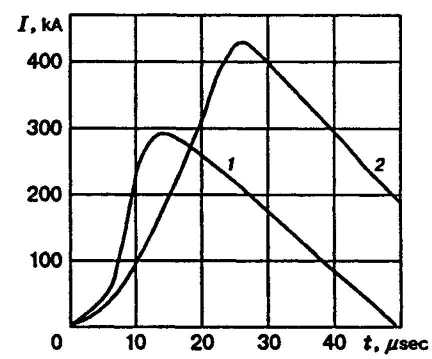

Fig. 4

end of MCG operation, the lower the load and generator currents and the steeper the current-pulse front. After termination of MCG operation, current flows for some time in the load circuit that formed and the action on the SCJ continues. However, because of the influence of the failing transformer unit, the current decreases rather rapidly (in about 30 μsec).

The primary inductance of the transformer is 18 nH, and the total final inductance of the primary circuit is 18.4 nH. The number of turns of the secondary winding of the transformer is decreased to 7.5 in the experiments. The experimental current curve 1 for this generator under a purely inductive load of 0.15 μH is given in Figs. 2 and 3.

The inductance of 0.15 μH is the same as the inductance of a similar facility in experiments with a capacitor bank [3]. These experiments show that the load resistance, determined by the jet and its contacts with the plates, varies from 5 to 8 mΩ for 55-mm-diameter charges, and for 100-mm calibre charges, it is approximately 10 mΩ. This value has already an effect on the generator operation, but it is not yet large enough, so that the approximation of effective inductance can be used to assess the MCG operation. In this approximation, the effective inductance of the generator circuit is $L_{1\,\text{eff}} = L_1 - 11.6$ nH in the experiments, and the effective resistance is $R_{1\,\text{eff}} = R_1 + 48.4$ mΩ.

In this case, to find the current curve at any moment of connection of the secondary circuit during generator operation, it only suffices to know two dependences of the current I_1 in the primary circuit of the transformer: when the secondary circuit is always closed and when it is always open. Figure 3 shows curves of $I_1(t)$ at no-load (curve 4) and for the cases where the SCJ completes the secondary circuit at 36 and 8 μsec prior to the end of generator operation (curves 2 and 3, respectively). In this case, the secondary-circuit

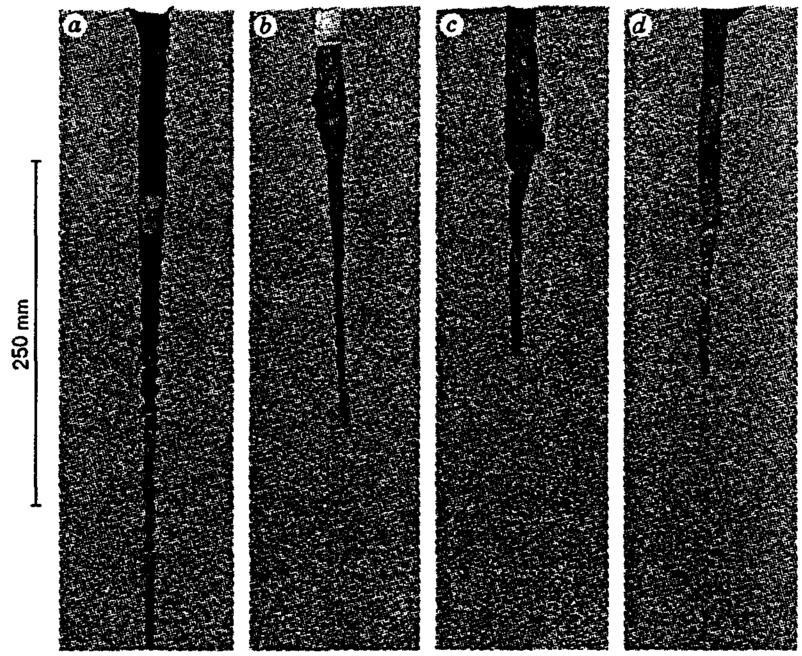

Fig. 5

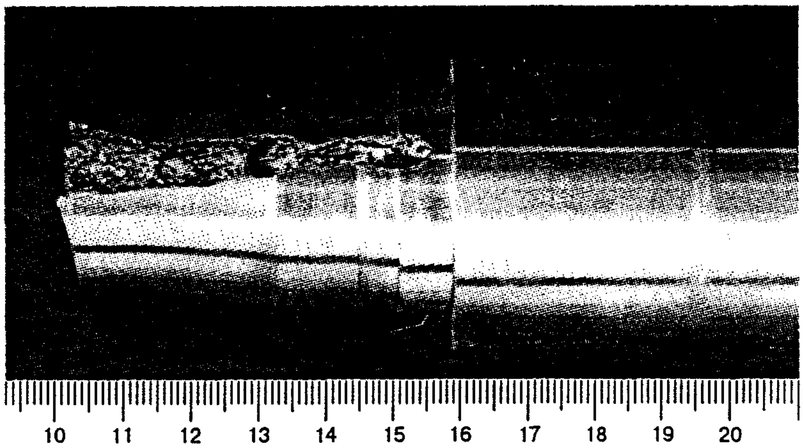

Fig. 6

current I_2 is regarded as induced current and can be determined from the formula

$$I_2(t) = -I_1 \frac{L_{12}}{L_2} + I_1^* \frac{L_{12}}{L_2} \exp\left(-\frac{R_2}{L_2} t\right) + R_2 \frac{L_{12}}{L_2^2} \exp\left(-\frac{R_2}{L_2} t\right) \int_0^t I_1(t) \exp\left(\frac{R_2}{L_2} t\right) dt,$$

where L_1, L_2, R_1, and R_2 are the inductance and resistance of the primary and secondary circuits, L_{12} is the mutual inductance of the transformer, and I_1^* is the primary-circuit current at the moment the secondary circuit is closed at time t^* prior to the end of MCG operation.

The time of explosion of the shaped charges was chosen so that the SCJ closed the contact plates at the specified time t^*. In the experiments, we used a shaped charge of diameter 55 mm, for which the penetration depth h_0 in ordinary steel is 190–200 mm, and a charge of diameter 100 mm ($h_0 = 460$ mm).

Experimental Results. Data of the experiments are given in Table 1.

The SCJ currents produced in experiment Nos. 1 and 2 are given in Fig. 2 (curves 2 and 3) and those obtained in experiment Nos. 3 and 5 are given in Fig. 4 (curves 1 and 2).

Figure 5 shows photographs of sections of cavities produced in a steel target by shaped charges of diameter 100 mm: the photograph in Fig. 5a refers to the experiment without a current, and the photographs in Fig. 5b–d refer to experiment Nos. 3–5.

Figure 6 illustrates a section of the cavity produced in a steel target in experiment No. 1. In experiment No. 1, the current front is flat (in experiment No. 2, a current of 200 kA is attained in 8 μsec and in experiment No. 1, it is attained in 18 μsec). Therefore the shape of the cavity is determined by the initial portion of the pulse. In experiment No. 2, a narrow curved channel is formed at the end of the current pulse because of the insufficient pulse duration. For $36 > t^* > 8$ μsec, the values of h will be smaller than those indicated in Table 1.

In experiments with charges of diameter 55 mm using a capacitor bank [1–3], a more considerable decrease in h (by a factor of 4) is observed at approximately the same current amplitudes. This is explained by the larger action integral of the capacitor-bank current compared to the action integral of the MCG.

In summary we note the following. The experiments performed showed the fundamental possibility of using a transformer MCG to disrupt a SCJ. Connection of a SCJ to an MCG circuit without a transformer (for example, in the circuit of a high-inductance helical MCG) will apparently involve more serious difficulties.

Extrapolation of the results of the experiments performed to larger charges (of diameter 200 mm and greater) suggests that a current pulse with an amplitude between 2.5 and 3 MA is required to act on SCJ from such charges. Such a pulse was produced by a K-160 type transformer generator [10] with secondary winding containing 5 turns. A current of 3.3 MA was produced using a modified K-160 generator with a ratio of the helix-to-pipe diameters of 2.5 into a purely inductive load of 0.2 μH. When the ratio of the helix-to-pipe diameters is 2, the current increases to 4.3 MA. The indicated currents and electric-pulse duration are quite sufficient for experiments with large-diameter charges.

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