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LECTURE DEMONSTRATIONS WITH PULSED MAGNETIC FIELDS

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IF a magnetic field is produced rapidly around a body having electric conductivity σ, then the field with penetrate into the body, within a short time t, only to a certain skin-layer depth $l \simeq c\sqrt{t/4\pi\sigma}$. The resultant field gradient will apply on the body a magnetic pressure $p_m = -\nabla H^2/8\pi$. This phenomenon is used in plasma accelerators for magnetic compression of the plasma (dc pinch, theta pinch). For a qualitative demonstration of the aforementioned magnetohydrodynamic effects it is very convenient to use metal conductors with suitably chosen mechanical and electrical characteristics.

We describe below demonstrations of radial compression of a metallic tube by a pulsed magnetic field, and also several effects connected with trapping of the field by the tube. A pulsed field was produced by discharging a capacitor bank into a solenoid surrounding the tube. The experiments were performed at first with tubes of 70–80 mm diameter, made of rolled and soldered copper foil 0.15 mm thick. However, more productive experiments were performed with machined duraluminum tubes of smaller diameter. Most employed tubes (T) had a diameter of 20 mm and a wall thickness 0.7–1 mm. With these parameters, the skin layer and the thickness of the wall were of the same order of magnitude; by varying either the wall thickness or the conductivity, it was possible to emphasize or attenuate the effects connected with diffusion of the magnetic field. If the skin layer is smaller than the wall thickness, then the effect of pure external pressure predominates. The resultant clamping of the cylinder produces characteristic folds (Fig. 2a) caused by loss of stability [1]. The use of a thinner wall leads to an appreciable diffusion of the magnetic field in the tube. When the field inside the tube reaches its maximum value and begins to drop off, the resultant induced currents retain the magnetic field inside the tube, so that the internal field exceeds the external one for some period of time, thus causing the inward motion of the wall to give way to outward motion. Photographs taken from the end of the tube have established that the tubes are initially compressed radially at a speed 200–300 m/sec, followed by outward spreading. Figure 2b shows photographs of the tubes after failure, and Fig. 3 shows the calculated time curves for wall thicknesses 0.75 and 1 mm (horizontal hatchures) at a initial capacitor voltage of 4.8 kV. The lengths of the hatchures indicate approximately the inside and outside external diameters. It is convenient to use an epidiascope for a detailed study of the deformed tubes.

By taking oscillograms of the derivative of the current and by suitable calculations, we determined the parameters of the discharge circuit without the tube. The damped-oscillation period was T = 80 μsec 75 μsec with the tube inserted, the total inductance

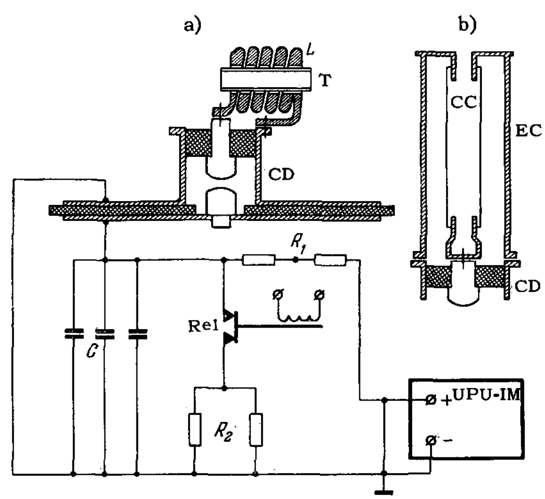

FIG. 1.

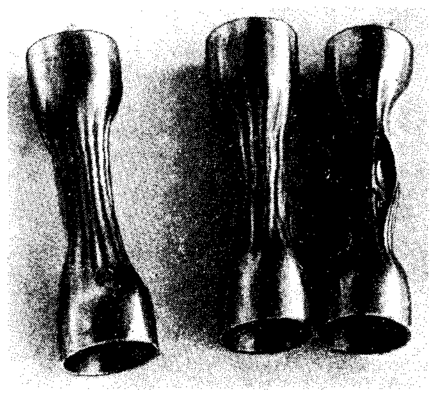

FIG. 2.

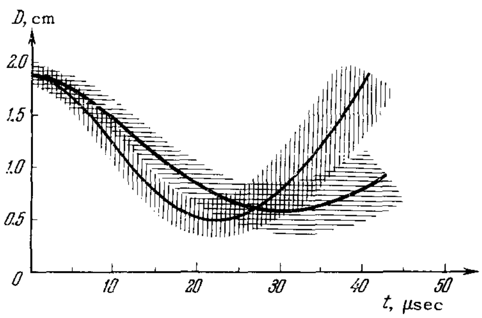

FIG. 3.

$L_0 = 0.38$ μh, the solenoid inductance $L = 0.25$ μh, and the capacitance 420 μF. The amplitude of the current during the initial half-cycle, at an initial capacitor voltage 4.8 kV, is $I_{max} = 130$ kA, the corresponding field at the center of the solenoid is $H = 100$ G, and the maximum magnetic pressure is $p_m \simeq 425$ kg/cm^2. The pressure acting on the tube inserted in the solenoid should greatly exceed this value, owing to the concentration of the field at the initial instant of time in the space between the solenoid and the tube.

The equipment can also be used to perform experiments on the compression of a conductor carrying a straight-line current. The solenoid is replaced by a short-circuited segment of coaxial line. Six rods whose ends are soldered into a flange form the external coaxial conductor of 70 mm diameter (EC). The central conductor (CC), which is to be compressed, is made up of several layers of copper foil 0.1—0.15 mm thick, rolled to a diameter of 20 mm. The upper end of the central conductor is fastened to the aforementioned flange, and the lower one to the central electrode of the discharge gap (see Fig. 1b and upper right of Fig. 4). In these experiments, the radial compression of the central conductor is clearly pronounced only at the fastenings; in the central part of the conductor, the picture is usually greatly complicated by different types of instabilities,

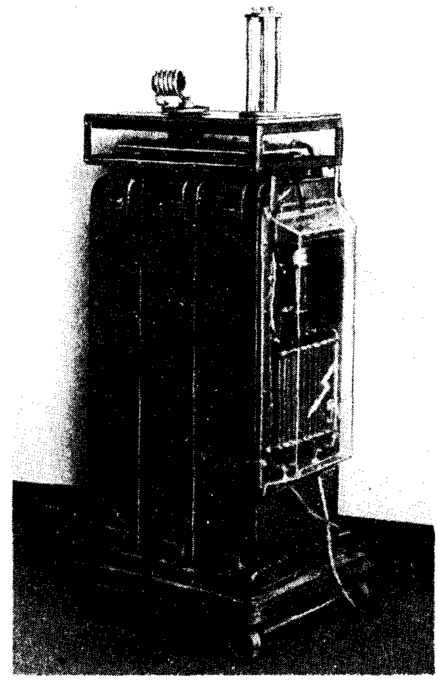

FIG. 4.

which are characteristic of plasma experiments.

A diagram of the setup is shown in Fig. 1a. C is a bank of capacitors of IM5-150 type, R_1 is the discharge resistance, made up of two PE 150 resistors, each rated 20 kΩ. "Rel" is a blocking relay with normally closed contact, obtained by modifying a KA relay by bringing out the contact group. R_2 is a blocking resistor consisting of two parallel-connected open helices, each 40 ohms, made of nichrome of 1 mm diameter; the construction is such as to ensure the required reliability and the possibility of continuously observing visually that R_2 is in good working order. The parts R_1, R_2, and Rel are mounted on a vertical panel suspended on the wall of the capacitor bank and covered with a transparent cover of organic glass (Fig. 4). The capacitors are interconnected with 4-mm brass bus bars with liners of vacuum rubber of 3 mm thick. The bus bar are tightened by through bolts with insulating washers. Mounted on the bus bar structure is a coaxial discharge gap CD, the outer conductor of which has a number of longitudinal slots to prevent damage by the shock wave produced during the discharge. The gap between the internal electrodes of 30 mm diameter can be regulated by moving the upper electrode. A welded housing, covered on the top with bakelite and on the side with organic glass, is placed over the bus-bar structure. The housing serves simultaneously to secure the capacitors, to protect the high voltage electrodes, and to serve as a table.

The solidly-machined brass solenoid contains four turns of 0.7×1.65 cm cross section, with a winding pitch of 10 mm and an inside diameter 25 mm. Discs with appropriate openings and slots, terminated by small lugs for mounting on the discharge gap, are soldered to the ends of the solenoid. Bakelite washers are placed in the gaps between the turns, and the internal working volume is insulated by a thin-wall vinyl plastic tube. The solenoid has sufficient strength and no further protection of the turns is necessary (a slight untwisting of the turns was observed only after 30—35 discharges).

When performing of the experiments, it must be borne in mind that the direction along the coil axis is dangerous, for if placed too far off-center in the solenoid, the tube can be ejected with high velocity

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[1] M. A. Lavrent'ev and A. Yu. Ishlinskiĭ, Dokl. Akad. Nauk SSSR **64**, 779 (1949).