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MAGNETIC CUMULATION

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Abstract

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MAGNETIC CUMULATION

It is known that an explosion is a powerful source of mechanical and thermal energy. In 1951 one of the authors (A. D. Sakharov) advanced the idea of the possibility of converting this energy into the energy of a magnetic field, and he also proposed the basic designs of sources of ultrastrong magnetic fields and currents based on the rapid deformation, by an explosion, of current-carrying circuits. Explosive-magnetic sources of this type were given the name MK generators (magnetic cumulation). The present article gives a brief description of the two most characteristic explosive generators: MK-1 (compression of an axial magnetic field) and MK-2 (expulsion of a magnetic field from a solenoid and its subsequent compression by the walls of a coaxial system).

The possibilities of explosive compression of an axial magnetic field were the subject of a short note by Ya. P. Terletskii ⁽²⁾. As later became known from the detailed article by Fowler, Garn, and Caird ⁽¹⁾, analogous experiments were being carried out at approximately the same time at the Los Alamos Laboratory (USA). There are no publications describing devices analogous to the MK-2 generator.

1. The MK-1 generator is a metal tube surrounded by a charge of explosive. An axial magnetic field is created inside the tube. By means of the explosive charge the tube is subjected to rapid symmetric compression. In this process its cross section decreases, and currents are induced in the walls of the tube that tend to keep the magnetic flux constant. For ideally conducting tube walls the magnetic flux

$$\Phi = \pi R^2 H = \pi R_0^2 H_0 = \text{const},$$

and the field strength and energy of the magnetic field increase inversely proportional to the square of the inner radius of the tube, i.e.,

$$H = H_0 R_0^2 / R^2, \quad W = W_0 R_0^2 / R^2.$$

Fig. 1

Figure 1: Fig. 1

Fig. 2

Figure 2: Fig. 2

Here R_0 , W_0 , H_0 are respectively the initial values of the inner radius of the tube, the energy, and the magnetic-field strength.

When a tube of finite conductivity is compressed, the magnitude of the magnetic flux decreases with time. The change in the magnetic flux is determined by the dimensionless parameter $\eta = \sqrt{4\pi\sigma Rv/c^2}$, where σ is the conductivity, $v = -dR/dt$. For $\eta \gg 1$ the flux is conserved. Let us note that when the tube walls move according to the special law $v \sim 1/R$, $\eta = \text{const}$, and the problem has an exact self-similar solution. The flux varies according to a power law $\Phi \sim R^\alpha$, where for large η , α is determined by the formula $\alpha = 2.26/\eta$.

Already in the first experiments with aluminum tubes of small diameter (~ 100 mm), magnetic fields with a strength of $1 \cdot 10^6$ oersted were obtained.

Subsequently, in one of the experiments with a stainless-steel tube, with a final diameter of the cylindrical cavity of ~ 4 mm, a value of H equal to $25 \cdot 10^6$ Oe was recorded. (Magnetic-field pressure $25 \cdot 10^6$ atm.) The oscillogram of the magnetic-field intensity obtained in this experiment is shown in Fig. 1. The portion of the field oscillogram with $H > 25 \cdot 10^6$ Oe went beyond the frame.

Fig. 1. Oscillogram of the magnetic-field intensity. Beam 1—the signal from short-circuited leads; beam 2—the signal from a measuring turn 1.5 mm in diameter (integration on an RC circuit)

The design of the MK-1 generator is shown in Fig. 2. In this experiment an HE charge was used, which ensured very rapid and sufficiently symmetrical compression of the tube. The initial magnetic field was produced by means of a coil made of aluminum foil wound on a stainless-steel tube. A capacitor bank was used to excite the current in the coil. The initial magnetic field penetrated into the tube (although it was not slit along a generatrix) owing to the sufficiently low conductivity of the stainless steel. The inner surface of the tube was coated with a thin (20μ) layer of copper (for more complete capture of the magnetic flux by the walls of the tube as they converged).

Fig. 2. MK-1 generator. 1—stainless-steel tube; 2—winding of aluminum foil; 3—HE charge.

When MK-2 generators, which will be described below, were used as the source of the initial magnetic field, strong magnetic fields were obtained in very large volumes (in an experiment with a copper tube 300 mm in diameter, a magnetic field of $5 \cdot 10^6$ Oe was recorded in a volume of 100 cm^3).

Fig. 3. MK-2 generator

Figure 3: Fig. 3. MK-2 generator

The attained values of the magnetic-field intensity apparently cannot be regarded as limiting. By ensuring good symmetry of the convergence of the tube walls toward the center and increasing their velocity, it is in principle possible to obtain arbitrarily large values of H , provided, of course, that

there will be no loss of conductivity of the tube walls when they are heated by extremely strong induction currents.

- II. The MK-2 generator consists of a central conducting tube and a coaxially arranged outer cylindrical spiral (solenoid), which passes into a solid cylinder (cup), the base of which is connected to the tube (see Fig. 3). A long cylindrical high-explosive charge is placed inside the tube, initiated at one point on the end face on the side of the spiral. (The high-explosive charge may be located outside the spiral and the cup.) A capacitor bank is discharged into the electrical circuit of the MK-2 generator, formed by the tube, the cup, and the spiral. Under the action of the explosion products, the central tube is stretched into the form of a cone, and at the moment when the magnitude of the discharge current passes through its maximum, its walls fly up to the beginning of the spiral.

Fig. 3. MK-2 generator

With further propagation of the detonation along the tube, a picture is observed analogous to the pushing of a metal cone at the detonation velocity into the spiral: the point of contact of the cone with the spiral moves along a helical line, the number of turns of the spiral remaining unshorted decreases, and, correspondingly, the inductance of the generator decreases. After the tube walls fly up to the beginning of the cup, the generator becomes a coaxial system whose length, and consequently whose inductance, decrease as the detonation propagates along the tube. The decrease in inductance is accompanied by an increase in the current I and the magnetic energy W . With sufficiently rapid continuous deformation of the circuit, the magnetic flux is conserved, i.e. $\Phi = LI \simeq L_0 I_0$, and

$$I = \frac{\Phi}{L} \simeq \frac{L_0}{L} I_0, \quad W = \frac{\Phi^2}{2L} \simeq \frac{L_0}{L} W_0,$$

where L_0, I_0, W_0 are the initial values of the inductance, current, and magnetic energy. The increase in magnetic energy occurs at the expense of the work performed against the ponderomotive forces of the magnetic field by the walls of the central tube.

With the aid of the MK-2 generator, currents of $5 \cdot 10^7$ A were obtained at a final inductance of $0.01 \mu\text{H}$. In some experiments the current was amplified

thousands of times and reached $1 \cdot 10^8$ A and more. With MK-2 generators, magnetic fields of $1-1.5 \cdot 10^6$ Oe were obtained in a very large volume, equal to several liters. It was possible to store energy of $1-2 \cdot 10^7$ J in the magnetic field. This energy amounted to 10-20% of the energy released in the explosion of the high explosive located in the tube inside the cup (during deformation of the cup (coaxial system), the magnetic flux is conserved).

- III. The consumer of electromagnetic energy may be connected to the MK-2 generator either directly (in this case the inductance of the consumer is the final inductance of the MK-2 generator and must be small), or with the aid of a transformer (the consumer is coupled to the circuit of the MK generator by inductive interaction).

Experiments have shown that, with the aid of a transformer, a considerable part of the magnetic energy obtained during explosive deformation of the circuit can be transferred to the consumer. (For example, from an MK generator of small diameter it was possible to transfer 50% of the magnetic energy.) This makes it possible, with the aid of an explosion, to concentrate significant energy in a consumer with comparatively large inductance, to move the consumer itself (and thereby protect it from the action of the explosion) to some distance from the MK generator, and also opens the possibility of creating

of a multistage MC system. In such a system the magnetic energy obtained in the first generator, whose source of initial energy is a permanent magnet, is transferred by means of a transformer to a second one, during whose operation this energy is amplified and transferred to a third, and so on.

Another method has also been implemented for transferring electromagnetic energy from the generator to an external load—by breaking an electrical circuit carrying current through the action of an additional explosive charge and transferring the magnetic flux from the final part of MC-2 into the load (the use of extra currents of interruption). In this way it proved possible to transfer to an external load (inductive and active) more than 50% of the energy generated by the MC-2 system. In a number of experiments the time for transferring the energy to the load was $0.5 \cdot 10^{-6}$ sec.

- IV. The field of application of MC generators is the solution of such problems of physics and engineering as, for example, the creation of comparatively small-sized single-action accelerators of charged particles to high energies (100–1000 Bev), the production and study of dense high-temperature plasma, the acceleration of dense formations to velocities of hundreds and thousands of kilometers per second, which is necessary for solving certain problems of astrophysics (attainment of stellar temperatures and pressures under laboratory conditions), shock-wave physics, the study of equations of state and of the properties of substances at ultrahigh temperatures and pressures, the study of the effect of meteorites on the skins of spacecraft, etc.

At present an MC generator has been developed for ironless betatrons of type

(³), and the first experiments have been carried out on remote feeding of the electromagnet of such accelerators. Experiments have also been carried out with coaxial-type electrodynamic accelerators. For aluminum foil with an initial mass of ~ 2 g, a velocity (of aluminum vapor) of 100 km/sec has been recorded.

Of very great interest is the performance of certain physical investigations in superstrong magnetic fields attained with the aid of MC generators, for example, the study of the influence of strong magnetic fields on the electrical resistance of metals and semiconductors, magneto-optical effects, etc.

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CITED LITERATURE

- ¹ C. M. Fowler, W. B. Garn, R. S. Caird, J. Appl. Phys., **31**, 588 (1960).
- ² Ya. P. Terletskii, ZhETF, **32**, 387 (1957).
- ³ A. I. Pavlovskii, G. D. Kuleshov, G. V. Sklizkov, Yu. A. Zysin, A. I. Gerasimov, DAN, **160**, No. 1, 68 (1965).

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