Suppression of an instability of the collapsing shell during magnetic concentration of energy

A. I. Pavlovskiĭ, M. I. Dolotenko, N. P. Kolokol'chikov, A. I. Bykov, N. I. Egorov, and O. M. Tatsenko

(Submitted 5 September 1983)
Pis'ma Zh. Eksp. Teor. Fiz. **38**, No. 9, 437–439 (10 November 1983)

An instability of the inner surface of the shell in a magnetic-compression generator of ultrastrong magnetic fields has been suppressed by using several coaxial cylinders in succession as the shell compressing the magnetic flux.

PACS numbers: 52.55.Ke, 84.60.Td, 85.70. – w

In effective conversion of the kinetic energy of a collapsing conducting shell which is compressing magnetic flux into magnetic field energy ("magnetic cumulation"[1]), the shell is stopped by the counterpressure exerted by the magnetic field being intensified. The stage is set for an unbounded development of configurational instabilities of the boundary between the material and the magnetic field. A particularly critical situation is the onset of an instability of the inner surface of the shell when its inner layer, which has been raised to a high temperature, loses its conductivity and its coupling with the magnetic field, while the conducting part of the shell behind this inner layer is decelerated by the magnetic field pressure. The resulting ejection of material into the magnetic-field region hinders or completely prevents research in the magnetic field of a magnetic-compression generator.

It has now been found possible to suppress this very serious restriction on the magnetic field level of this generator or ultrastrong magnetic fields by using several coaxial cylinders in succession as the shell compressing the magnetic flux. Initially, the cylinder is formed by closely packed but electrically insulated fine copper wires arranged parallel to the axis of the cylinder, embedded in an epoxy compound.[2] Since there is no conductivity in the azimuthal direction, the flux of the axial magnetic field can diffuse through the cylinder in its initial state; after this cylinder is struck by the incoming earlier cylinder, it converts into a metallic cylinder with a good conductivity, which traps and compresses the magnetic flux in its cavity.

The present experiments were carried out with a magnetic-compression generator of reproducible ultrastrong magnetic fields with a shell with an initial inside diameter of 139 mm (Refs. 3 and 4; we call this the first cylinder and an initial magnetic field of 160 kG. Positioned coaxially with the shell, in its cavity, are the second and third wire cylinders with inside diameters of 28 and 12 mm. The effect of this cascade arrangement on the shape of the inner surface of the contracting shell was studied by irradiating the entire generator with the bremsstrahlung from a pulsed ironless betatron[5] in the direction along the axis of the generator. In each experiment we obtained a single photograph showing a cross section of the shells in the generator.

The resulting x-ray photographs clearly demonstrate how the series of cylinders affect the changes in the shape of the inner surface of the shell compressing the ultrastrong magnetic field. Figure 1 shows three successive x-ray photographs of a two-

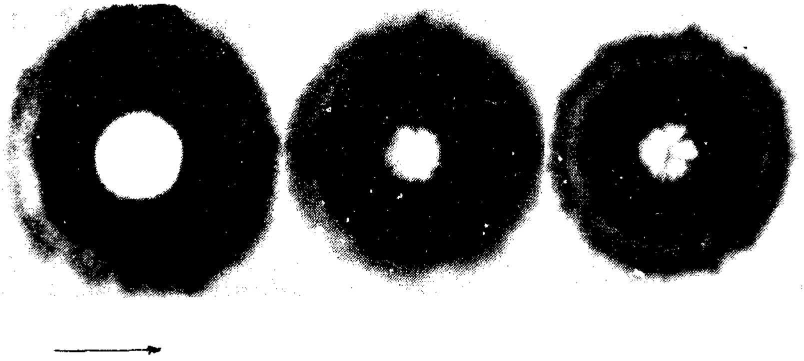

FIG. 1. Series of x-ray photographs of a two-cylinder generator taken at time intervals of $\sim 1\ \mu s$.

cylinder generator, taken at intervals of $\sim 1\ \mu s$. The third photograph in this series was taken at the time closest to the maximum value of the magnetic field (~ 8 MG) in the cavity of the second cylinder. The inner surface is nearly circular on the first photograph, with slight, smooth, long-wavelength deviations. On the second photograph we see the initial stage of the development of perturbations at the boundary between the shell and the magnetic field: the formation of cumulative jets, which begin as short, thin points, and subsequently collide at the center, entraining in the process a progressively greater mass of the shell of the second cylinder (as shown in the third photograph).

The third cylinder completely resolves the problem of the instability of the surface of the shell compressing the magnetic field, which reaches 9–10 MG, up to the time of the maximum magnetic field. Shown at the left in Fig. 2 is a photograph of a three-cylinder generator taken precisely at the time of the field maximum. Here the inner boundary of the shell is smooth, and its minimum diameter is about 11 mm. Between the cylinders we see gaps in which some of the initial magnetic flux is lost. The photograph at the right in Fig. 2 shows for comparison the state of the inner surface of the shell of a single-cylinder generator, also near the time of the maximum field in its cavity. The photograph at the center is of a three-cylinder generator, taken $\sim 1\ \mu s$ later. We set from this central photograph that the boundary of the cavity with the multimegagauss magnetic field nevertheless loses its shape, and characteristic jet-

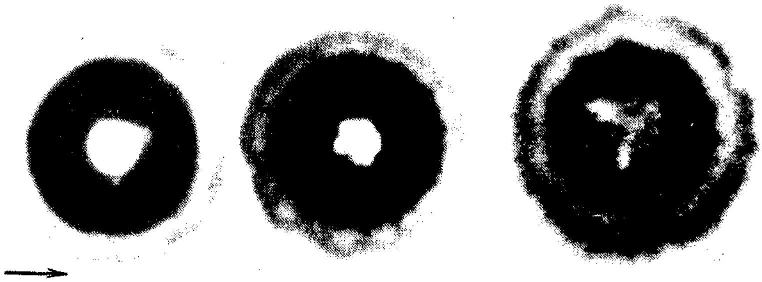

FIG. 2. x-Ray photographs of a three-cylinder generator and a single-cylinder (at the right).

like ejections of matter occur toward the contraction axis.

A complete and accurate description of the interactions of the cylinders with each other and with the ultrastrong magnetic field requires two-dimensional calculations and a detailed understanding of the properties of the material at high energy densities. The effect of the cylinders on the course of the instabilities can apparently be explained at a qualitative level as a replacement of the material of the first cylinder, heated above the boiling point, by the cold material of the second cylinder. At this point, the perturbation growth rate decreases, and the time interval over which the peturbations grow is itself much shorter. At the next cylinder, this replacement of material is then repeated. The conditions become even less favorable for the development of perturbations. Another very important circumstance is that the position of the next cylinder is chosen such that the perturbations in the shape of the preceding cylinder have not yet managed to grow to a significant level. The changes in the conditions at the surface which bound the magnetic field may also be related to a superheating of the material. Material in a super-heated state, into which energy is being pumped so rapidly that the material has not had time to evaporate, retains its conductivity, so that the expansion of the surface layer of the shell is limited by its interaction with the magnetic field. The state of the accelerated injection of energy into the material prevails when each successive cylinder comes into play.

This study of the operation of a multistage magnetic compression generator has revealed the variety of mostly interrelated functions of the cylinders. The stabilization of the magnetic-flux compression described above appears to be the most important function of the cylinders, making it possible to increase the magnetic concentration and to reproducibly obtain magnetic fields in the 10-MG range.

[1]R. Z. Lyudaev, E. N. Smirnov, Yu. I. Plyushchev, A. I. Pavlovskiĭ, V. K. Chernyshev, E. A. Feoktistova, E. I. Zharinov, and Yu. A. Zysin, Dokl. Akad. Nauk SSSR **165**, 65 (1965).
[2]N. P. Kolokov'chikov, G. I. Ivanov, Yu. I. Plotnikov, and V. N. Rubashkin, USSR Patent 311582; Byull. Izobret. **32**, 239 (1979).
[3]A. I. Pavlovskiĭ, N. P. Kolokol'chikov, M. I. Dolotenko, and A. I. Bykov, Prib. Tekh. Eksp. No. 5, 195 (1979).
[4]A. I. Pavlovskiĭ, N. P. Kolokol'chikov, O. M. Tatsenko, A. I. Bykov, M. I. Dolotenko, and A. A. Karpikov, Megagauss Physics and Technology, Plenum, New York, 1980, p. 627.
[5]A. I. Pavlovskiĭ, G. D. Kuleshov, G. V. Sklizkov, Yu. A. Zysin, and A. I. Gerasimov, Dokl. Akad. Nauk SSSR **160**, 68 (1965).

Translated by Dave Parsons
Edited by S. J. Amoretty