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An Explosive-Driven High Field System for Physics Applications*

by

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ABSTRACT

A simple explosive-driven flux compression system is described for producing magnetic fields in the megagauss range. The flux-trapping device is a seamless hollow stainless steel cylinder driven by a ring of explosive. The initial field is introduced by a coil pair supplied by a 90 kJ capacitor bank. The assembly is readily evacuated. During implosion, the experimental volume is free of objectionable debris and asymmetries. Peak fields of 1.2 and 4 MG are achieved in working diameters of 8.9 and 3.2 mm, respectively. The usable length is about 15 mm at these fields. Several possible applications are mentioned.

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DISCLAIMER

The use of explosives makes it possible to achieve multi-megagauss magnetic fields in small but usable working volumes. Previous publications[1,2] discuss the principles and techniques involved. Briefly, an axial magnetic field is induced within a hollow conducting cylinder or liner by discharging a condenser bank through adjacent coils. A ring of explosive around the liner is detonated on the periphery. The resulting implosion drives the conductor radially inward, compressing the initial field to high values.

There are several different techniques for introducing the initial field into the liner volume and then trapping the flux during the implosion. One method is to use a coil internal to a copper liner. The liner must be slotted and the slot insulated in order to admit the flux. This slot is then closed to make a good electrical contact when the detonation front reaches the liner. Some of our highest fields have been reached with such a system, and it is very useful for some experiments. However, it has serious drawbacks for many physics applications. The presence of the coil within the high field volume gives rise to jetting and perturbations of the liner surface during implosion. Such perturbations may destroy the experimental assembly before maximum field is achieved. Also, the lighter insulating material tends to run ahead of the conducting surface. This debris in the high field region is undesirable in many cases. The slot in the liner causes similar difficulties during implosion. Finally, it is often necessary to evacuate the liner volume to prevent gas shock waves or to provide cryogenic insulation. It is difficult to make a vacuum-tight assembly with an insulated slot.

It is evident that techniques which use a slotted liner or a coil beneath the explosive charge have limitations. The ideal system should have a seamless liner with the initial field introduced by coils on either side of the explosive. One can use a dc field with a highly conducting liner, or a slowly rising pulsed field with a poorly conducting liner. We have chosen the latter method since it lends itself to higher fields with the energy sources available. The liner material used is 18-8 stainless steel. It is sufficiently resistive to allow establishment of the slowly rising initial field, but conductive enough to trap flux during the much more rapid implosion.

Figure 1 shows a typical shot assembly. The 347 stainless steel liner is 4-1/4 inches in outside diameter and 4 inches long. The wall thickness is varied to suit the experiment. The explosive is a ring of Composition B[1], 9-1/4 inches in outside diameter, 3 inches long, and 4-1/4 inches in inside diameter. Twenty-five detonators are equally spaced around the outside in the midplane. The coils on either side of the charge consist of 8 turns of 1/4 inch by 1/10 inch Formvar-coated wire on phenolic forms. The field probes or other apparatus are supported by the Lucite end caps. The assembly is easily sealed and evacuated.

The coils are energized by a 435 μF, 20 kV capacitor bank. Peak field is reached 160 to 205 μsec after the bank is triggered, depending upon the liner thickness. With 16 kV on the capacitors and no liner, the field is 33.5 kG on the axis in the midplane. A 1/16 inch wall liner reduces this field to 25 kG. A 1/4 inch liner gives only 14 kG. The detonation is timed so that the liner starts to move when the initial field is at its peak.

The magnetic field achieved for a given explosive-liner configuration during implosion is proportional to the initial field up to the point where the magnetic pressure begins to slow down the liner. In fact, the theory indicates that the pressure becomes sufficient to reverse the liner motion, setting an upper limit on the field obtainable. The present systems, with initial fields of only a few tens of kilogauss, are limited more by the degree of symmetry of the implosion and the diameter into which experimental arrangements can be squeezed.

It is useful to define a field compression ratio α which is the ratio of the compressed field to the initial field. For the fields used here, α is independent of the initial field. This quantity α is plotted in Figure 2 against the time after the first liner motion. It is evident that the time scale of the field buildup can be varied by changing the liner thickness.

The highest fields are attained by the 1/16 inch thick liner, since the initial field is higher. For an initial field of 25 kG, a field of 1.2 MG is obtained in a working diameter of 8.9 mm. The usable length is about 15 mm. For an initial field of 20 kG, a field of 4 MG is obtained in a working diameter of 3.2 mm. This latter case corresponds to an α of 200. The high compression ratio indicates excellent implosion symmetry. We are increasing the capacitance of our bank in order to reach still higher fields in the same volumes.

There are a number of applications for this high field system. At present, W. B. Garn is completing measurements on the Faraday rotation in quartz using the mercury green and blue lines. The experimental assembly consists of a mercury lamp, a polarizer, a quartz cylinder 5-10 mm long, a second polarizer, an interference filter, and a photomultiplier detector. As many as two full rotations have been observed at fields up to 1.8 MG. Since air shocks cause the quartz to luminesce, it is necessary to evacuate the liner for this experiment.

We also are exploring the feasibility of measuring Zeeman splittings with a sweep spectrograph and magnetic susceptibilities with balanced pickup loops.

Footnotes

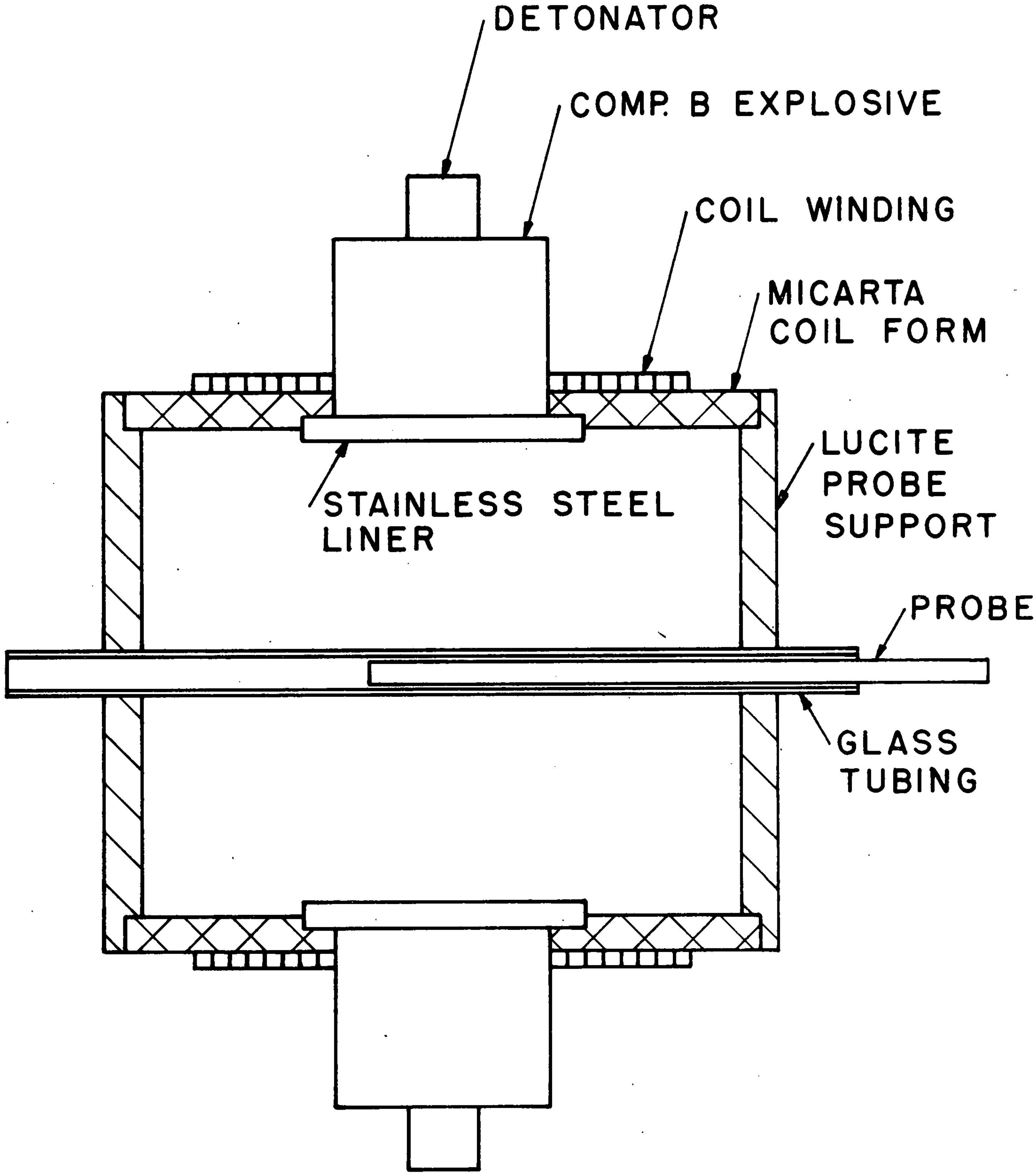
[1] C. M. Fowler, W. B. Garn, and R. S. Caird, J. Appl. Phys. 31, 588 (1960).

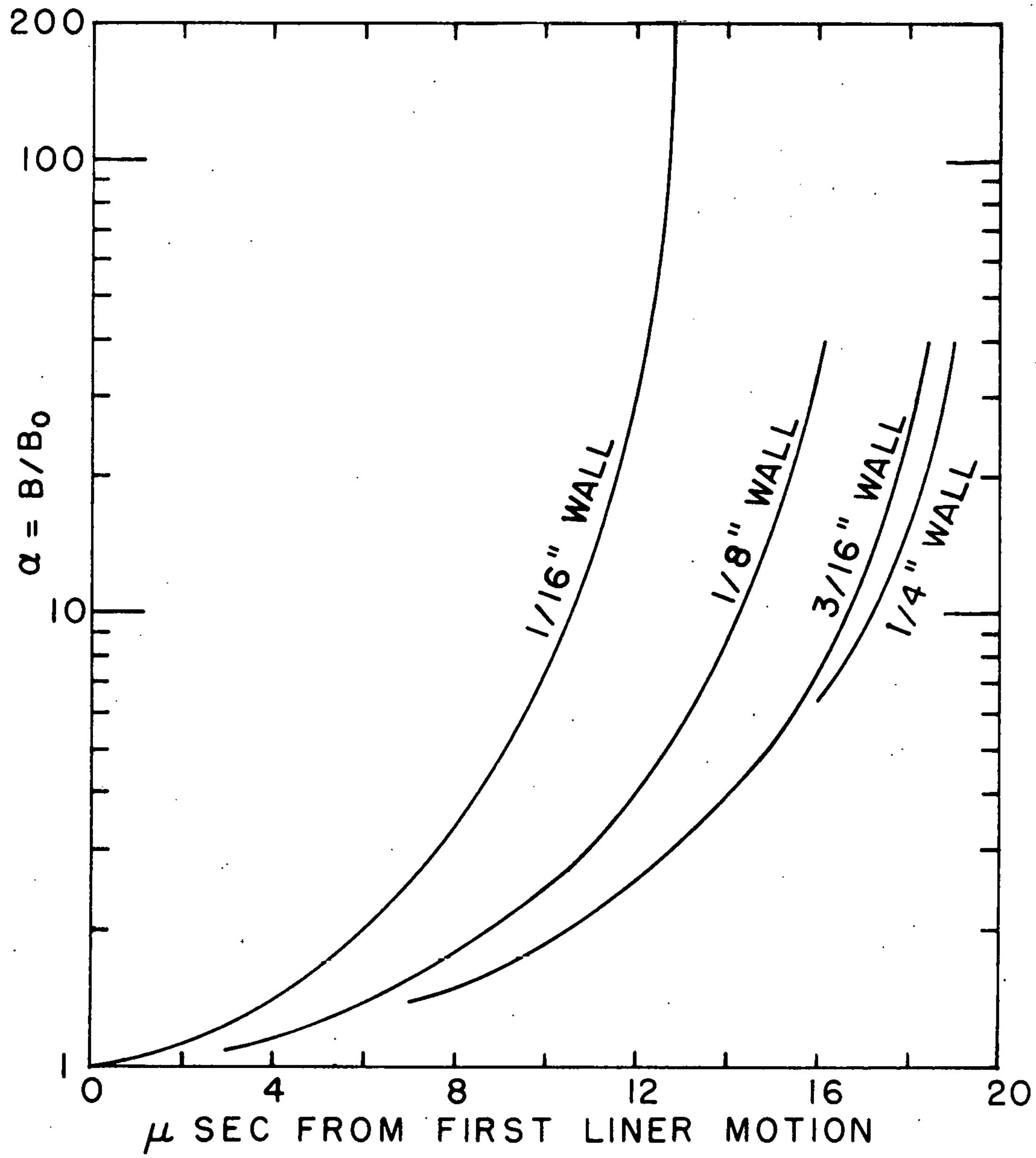
[2] C. M. Fowler et al. in High Magnetic Fields, edited by H. Kolm, B. Lax, F. Bitter, and R. Mills (M.I.T. Press, Cambridge, Massachusetts, 1962), p. 269.

Figure Captions

Figure 1. Cross-section view of a typical shot assembly.

Figure 2. Field compression versus time curves for the cylindrical implosion of stainless steel liners. α is the ratio of the compressed field to the initial field. Time is measured from the first detectable liner motion.


DETONATOR
COMP. B EXPLOSIVE
COIL WINDING
MICARTA COIL FORM
LUCITE PROBE SUPPORT
STAINLESS STEEL LINER
PROBE
GLASS TUBING



200
100
10
1
0
4
8
12
16
20
α = B/Bo
1/16" WALL
1/8" WALL
3/16" WALL
1/4" WALL
μ SEC FROM FIRST LINER MOTION