TITLE: EXPLOSIVE GENERATION OF HIGH MAGNETIC FIELDS IN LARGE VOLUMES AND SOLID STATE APPLICATIONS

AUTHOR(S): C. M. Fowler, R. S. Caird, D. J. Erickson, B. L. Freeman and W. B. Garn

SUBMITTED TO: OJI International Seminar on the Application of High Magnetic Fields in Physics of Semiconductors and Magnetic Materials, Hakone, Japan, 10-13 September 1980

LOS ALAMOS SCIENTIFIC LABORATORY

EXPLOSIVE GENERATION OF HIGH MAGNETIC FIELDS IN LARGE VOLUMES AND SOLID STATE APPLICATIONS*

C. M. Fowler, R. S. Caird, D. J. Erickson, B. L. Freeman and W. B. Garn
Los Alamos Scientific Laboratory
University of California
Los Alamos, NM 87545, USA

Abstract

Various methods of producing ultra-high magnetic fields by explosive flux compression are described. A survey is made of the kinds of high magnetic field solid state data obtained in such fields by various groups. Preliminary results are given for the magnetic phase boundary that separates the spin-flop and paramagnetic regions of MnF_2.

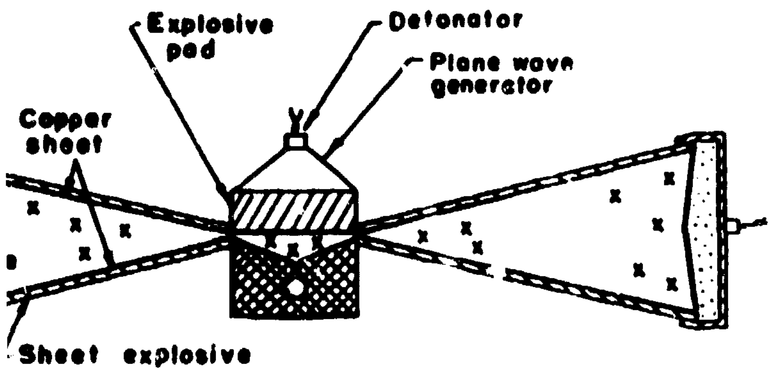
1. Introduction

This year marks the twentieth anniversary of the first description of devices that produced ultra-high magnetic fields (1000-1500 T) by explosive flux compression techniques [1]. These devices rely upon the explosive cylindrical implosion of a thin walled conducting cylinder, usually called a liner, that contains an initial magnetic field. To the extent that flux is conserved within the liner, the initial magnetic field is amplified inversely as the square of the liner radius as it implodes. Since these early experiments similar results have been achieved at several other laboratories. However, as will be noted later, these systems have been exploited very little as research tools. On the other hand a certain amount of scientific information has been obtained in the range of 100-200 T with other types of explosive flux compression systems. There are some distinct advantages to these systems that partially offset the difficulties in using explosives. The initial magnetic fields required can be supplied by relatively slow capacitor banks, they can generate large fields in volumes substantially larger than those obtained by other methods; they can develop much larger fields than those obtained by other methods, at least to date.

A brief description of various high field systems with representative field volumes and time histories is given in section 2. Included here are speculations on the magnitudes of ultra-high fields that might be produced within the next few years. In section 3 we present the results of recent measurements made to obtain the temperature dependence of the magnetic phase boundary that separates the spin-flop and paramagnetic regions in MnF_2. Very preliminary results are described that were obtained from a new rotating mirror spectrograph with optics designed for the near ultraviolet.

2. High Field Systems

Fields to 250 T



: drawing of a two stage high field generator.

:st stage consists of two strip generators connected in series
-stage but fired in parallel. We describe first the strip
› they are also used individually to generate fields up to
case, the load coils are normally made from 51 mm square brass
› long. A hole of the appropriate diameter is drilled through
output ends of the generator plates are connected to the load
m to the faces formed by machining a slot from one side of the
.e. The explosive layers consist of two sheets each of Dupont
The sheets are about 340 mm long and 95 mm wide, into the
;ure, with a combined mass of approximately 1.6 kg. The angled
'e 1.6 mm thick, 340 mm long and are separated by 100 mm at the
ıd. To enhance the structural strength of the plates they are
ıut 20 mm on the long sides to form troughs that, in turn, hold
rips. The inside dimensions of the troughs are about 100 mm.

's characteristic field vs time curves obtained for several
ers. The peak fields obtained for a given system are
stent, usually varying no more than one or two percent for the
diameters. Not plotted on Fig.2 are results for 9 mm D
ak fields are somewhat more variable, ranging from
n interesting variant of this class of generators has been
LACH et al. [2]. Here, the explosive is sandwiched between
pper which are, in turn, driven outward to contact stationary
. The outer conductors can therefore be made quite massive,
by concrete, to make them quite resistant to distortion from
BICHENKOV [3] has achieved conversion efficiencies of
netic energy approaching 15% with similar systems. We have
ots with devices of this type. Their performance is at least
ıe particulars superior to those shown on Fig.1. However, they
more expensive to fabricate.

description of the two stage system used for higher fields.
and load coil are machined from a single piece of brass bar
'6 mm deep, into the plane of the paper, 180 mm wide and 76 mm
gular cavity, or second stage, is normally about 150 mm wide
t the triangle apex. Initial magnetic fields are supplied by
and fill both first and second stage cavities as well as the
coil. The second stage is initiated at such a time as to

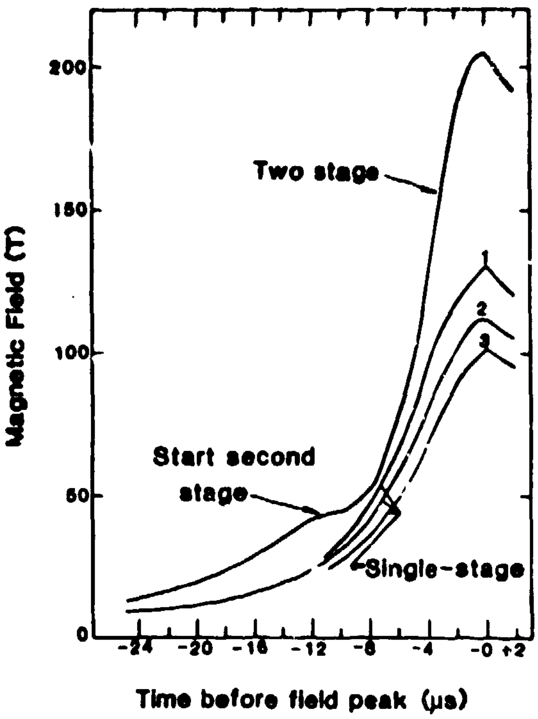


Fig.2 Field vs. time plots for single and two-stage systems. Load coil diameters for curves 1-3 are 11.1, 15.9 and 19.1 mm.

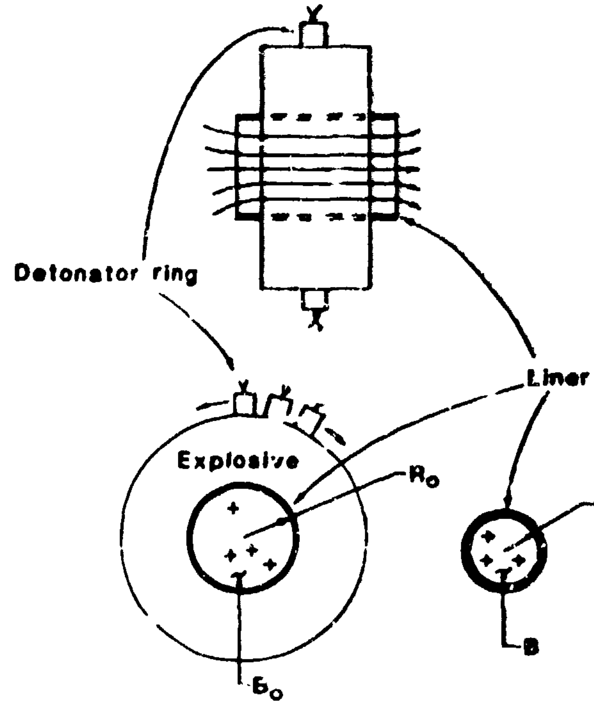


Fig.3 Schematic drawing of a cylindrical implosion system.

initiator and a high explosive pad, normally 76 mm high, 76 mm deep and 155 mm long. The explosive used most often is a plastic bonded type, 95% HMX and 5% binder. The P081 plane wave initiator is available from Los Alamos. HERLACH and his collaborators [2] have used a related two-stage system. They achieved simultaneous plane initiation by using a metal flyer plate to impact the explosive.

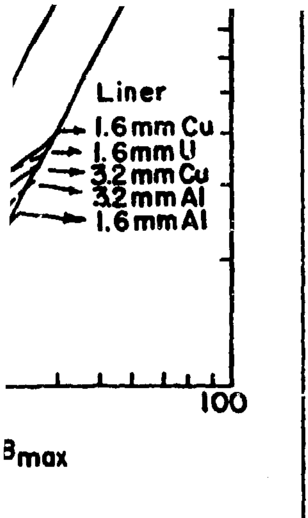
A typical field vs time plot for this system is given in Fig.2 for a field coil 15.9 mm in diameter and 76 mm long. This record may be compared with that obtained from a single stage device with the same sized load coil that is also shown. The single-stage devices are quite forgiving in that about the same peak fields are obtained from similar systems, even with variations of several percent on metal thickness, explosive thickness and width, the angle between the copper plates and the initial energy supplied to the system. We have found that the two-stage devices are more demanding. In our systems, for example, performance seems to degrade if the magnetic fields at the start of the second stage depart appreciably from the range of 35-45 T. Generally, peak fields obtained with a given system vary from shot to shot by 2-3%, and up to 5% for the smaller diameter, higher field shots. Typical peak fields for other load coils are 170 T and 240 T for diameters of 19.1 and 9.5 mm respectively.

Cylindrical Implosion Systems: fields to 1500 T

:ne aiscussion or nign magnetic fields as
ıerly belong to this conference. However, for
a short discussion of high field compression of
found in [14].

ıt al. [15] quote production of fields of 500 T
l 1500 T in coils of 7 mm diameter. This same
:ly reported Faraday rotation data obtained with
of about 950 T. To our knowledge, this is the
ıtate data yet obtained.

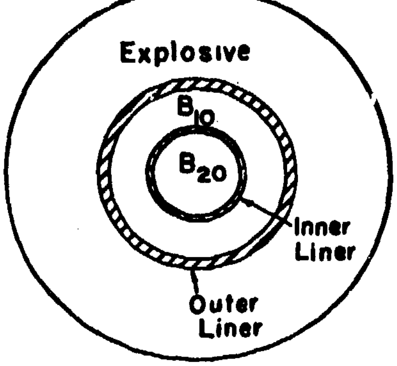
with one other explosively driven cylindrical
:IO et al. [17], that has been used for high
ıearch. It employs a thin-walled cylindrical
inside of which a magnetic field has been
ıxplosive is initiated at one end of the
ence. The implosion is thus quasi-cylindrical
ıgnetic field that moves along the axis of the
n velocity. Fields in the neighborhood of 400 T
levices. GUILLOT and LE GALL [18] have observed
-optic properties of yttrium-iron garnet,



ı field and compression ratio for ı, B_o. The dimensions of the HMX l 107 mm ID.

ons. At present, we think that our : up to radial liner compressions ls based upon observed magnetic 200 to 1 with stainless steel of the initial flux had diffused tion. According to Fig.4 if the ions of 35 to 1, then fields of liners, provided that no more than iffusion into the liner. The the explosive charge is to raise studied. This has the effect of given final field, but also itial field.

figurations using a one-dimensional over that first employed by KIDDER ls occur somewhat in advance of .ty of flux diffusion at this time. fields near 4000 T in diameters of :er than 90% of peak of 0.2-0.25 μs. :s must be treated with great aracterizing the physical properties required in the calculations. A dimensions of the system as, for dynamical time scale would be n into the liner would vary as a



B_{10}	B_{20}	B_2 (peak)	Diam (min)
5 T	5 T	2130 T	2.31 mm
10	5	2320	2.21
10	10	1880	3.47
15	5	2360	2.19
15	7.5	2080	2.86
15	10	1930	3.46

Fig.5 Idealized calculations for combined explosive-electromagnetic flux compression system. The dimensions of the HMX explosive charge were fixed at 235 mm OD and 108 mm ID. The wall thickness of both aluminum liners is 1.6 mm, and the OD of the inner liner is 51 mm.

As is seen in Fig.5, an inner liner is added to the system shown in Fig.4. The experimental region is centered inside the inner liner, which has an initial magnetic field B_{20}. This liner is then driven magnetically by the field between the two liners, with initial value B_{10}. The explosive system and initial liner dimensions are not varied. Peak fields and turnaround diameters are given for various initial field values, B_{10} and B_{20}. The calculations are completely idealized in that flux inside the liners is conserved. Only a few calculations have been made. It is likely that results similar to those shown in Fig.4 can be predicted with other materials and configurations. A few calculations have been made where several concentric liners have been placed in one flux compression system, each liner in turn, being driven by its adjacent field. However, no striking improvements in high field generation have as yet been obtained.

3. Solid State Data: <200 T

Examples of data obtained with cylindrical implosion systems were mentioned in the preceding section. We mention here a few examples obtained from strip systems or two stage systems, generally in fields in the 100-200 T range. Since this report is limited to explosively produced fields we do not include, for example, the beautiful cyclotron resonance experiments in megagauss fields of HERLACH et al. [22] and of MIURA and his collaborators [21]. These experiments usually involved the analysis of laser light reflected from the surface of various materials placed in high fields obtained by electromagnetic liner implosion. They could also be carried out in explosively produced fields, perhaps with some advantages, but have not been done to our knowledge. Almost all of the information in this category has been obtained either by DRUZHININ and his associates [23] or by the Los Alamos group. Generally speaking, the first group employed the Faraday effect using a single wavelength of light obtained from a laser. Most of the work reported by the Los Alamos group also involved optical effects both in the Faraday mode and i