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Pulsed Electrical Power from Explosives

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INTRODUCTION

The Los Alamos Scientific Laboratory (LASL) is developing new ways to generate high-energy pulsed power through the explosive compression of magnetic flux. Simply stated, such generators convert part of the chemical energy in high explosives into powerful bursts of electromagnetic energy. Similar work is being conducted for the US Energy Research and Development Administration (ERDA) at the Sandia and Lawrence Livermore laboratories, and is under way in the USSR and France. LASL pioneered this field and in continuing its own program has worked in collaboration with other Department of Defense (DoD) and ERDA laboratories. The LASL efforts described here require a multidisciplined approach involving physics, engineering, and materials sciences. For example, our expertise in high explosives and detonation devices has been essential to these efforts.

Explosive generators are now capable of delivering millions of joules* of electrical energy in times of the order of millionths of a second, or, in other words, very large but very short pulses of power. Several unique features of explosive generators make them attractive as pulsed-power sources for numerous applications. Some of these features are as follows.

- *Compactness.* There are increasing research and military needs for portable, low-weight and low-volume, high-output pulsed-power supplies. Explosive generators can satisfy many of these needs. A rocket-borne plasma physics experiment described below illustrates this feature.
- *Small relative cost.* Explosive generators offer a low-cost pulsed-power alternative for use in feasibility or proof-of-principle experiments. For example, initial experiments in controlled-fusion research for peaceful energy needs may be powered by these devices before large investments are made for permanent, conventional power supplies.
- *Very high magnetic fields.* Explosive generators have been used to make the largest magnetic fields ever measured. These fields can be made over large volumes for materials and special-effects testing.

MAGNETIC FIELDS

To understand how explosive generators can produce high-energy pulsed power by compressing

*One million joules of energy is roughly that contained in half a pound of TNT.

magnetic fields, we need to understand something about how magnetic fields behave. When electric current is passed through a metal coil, the strength of the magnetic field thus established is proportional to the amount of current. Although magnetic fields are distributed continuously in space, it is often helpful to picture them as consisting of several lines (filaments) that are drawn more closely together in regions where the fields are stronger. Figure 1 shows the magnetic-field pattern produced by a current flowing around a thin, metallic, cylindrical coil. Current enters and leaves the coil through parallel plates connected on either side of a "feed" slot in the coil. The arrows on the filaments show that the magnetic fields are also directed in space.

The energy required to generate a magnetic field depends upon the strength and volume of the field. Once the field is established, this energy is stored in the field and is available under appropriate conditions for other energy needs.

Magnetic field lines can pass freely through nonconductors of electricity, but they have difficulty in passing through good electrical conductors in short times. In turn, magnetic fields exert pressure on these conductors that depends upon the square of the magnetic field's strength. If the feed slot in the coil of Fig. 1 is shorted (closed), the magnetic field lines in the coil will then be completely surrounded by metal and thus will have difficulty in leaving the coil. The total number of lines (magnetic flux) in the coil will therefore tend to be conserved—in effect, we will have stored energy in the magnetic field.

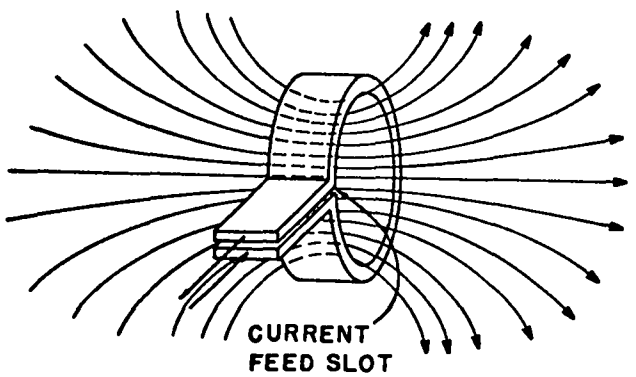


Fig. 1.

CONVENTIONAL PULSED POWER

Power is the rate at which energy is delivered. We normally think of continuous power delivered through our electrical power lines from large generating plants. There are, however, increasing demands for very large bursts of energy in short times, that is, high-energy pulsed-power bursts. Figure 2 shows one conventional way in which such pulsed power is delivered to a load coil, such as that shown in Fig. 1. Energy taken slowly from the ac power lines is stored electrically in a "capacitor bank"* after being converted to dc high voltage through a "converter." When switch S_2 is closed, the electrical energy stored in the capacitor bank is transformed to magnetic energy in the coil. Large capacitor banks can transfer energy in the million-joule range in a few millionths of a second, thus delivering energy to the coil at very high power rates.

PULSED POWER FROM EXPLOSIVES

Figure 3 shows a type of explosive generator called a plate generator, together with a cylindrical load coil to be energized. The plate generator consists of a metal box whose top and bottom plates are overlaid with slabs of high explosive. An initial magnetic field is produced in both the plate generator and the coil from a small capacitor bank connected across the feed slot. To this point the technique is conventional, but now the new element of explosive flux compression begins. When the slabs of explosive are detonated, they begin to drive the top and bottom plates of the box inward. Almost immediately the top plate closes off the input feed

*A capacitor bank can be thought of as a specially designed battery capable of discharging all of its energy in a small fraction of a second.

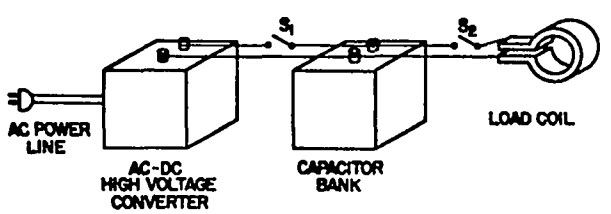


Fig. 2.

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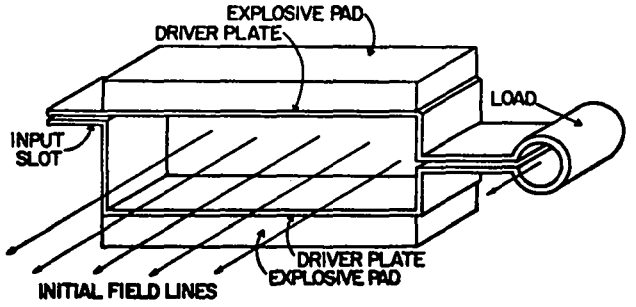


Fig. 3.

slot, thus trapping the field lines (flux) in an all-metal system. As the plates continue to move inward the magnetic field, current, and energy increase in the load coil, until finally much more magnetic energy appears in the coil than was originally in the system. The additional magnetic energy comes from energy in the explosives as they drive the metal conducting plates against the magnetic-field pressure. Because the energy can be delivered very rapidly, the coil can be powered at extremely high levels.

The components of Fig. 2 are not drawn to scale. In most applications, the converter and especially the capacitor bank are large and heavy (and expensive). However, owing to the very large energies available in explosives, very large energy and power delivery can be realized in explosive generators that use much smaller conventional sources to supply the initial magnetic fields.

Several conventional power-conditioning techniques can be adapted to explosive-generator output pulses to satisfy widely differing power requirements. These techniques include switching, pulse sharpening, and the use of transformers to step up pulse voltages. To meet various load requirements, explosive generators may vary widely in construction, both in the form of the metallic conductors and in the shapes and kinds of high explosives used.

APPLICATIONS

Experiments are now being carried out at LASL to develop pulsed x-ray and neutron sources (for radiography of other explosive devices, and possibly for use as weapon effects simulators) that will likely cost much less than fixed installations or underground nuclear tests. Preliminary analysis indicates that such power sources could also be used to power relativistic electron-beam machines and certain high-power microwave radiating devices.

Explosive-generator power supplies have application in experiments requiring compact, portable power supplies. For example, in an experiment done in collaboration with Sandia Laboratories, a STRYPI rocket (Fig. 4) was flown that contained a plasma gun powered by an explosive generator. This gun injected into the Earth's magnetosphere high-speed ionized particles that were needed for a physics experiment in the upper atmosphere. In a normal laboratory operation, a conventional power supply for the plasma gun would weigh 9 or 10 tons and have a volume of several cubic yards. The rocket experiments were possible because the

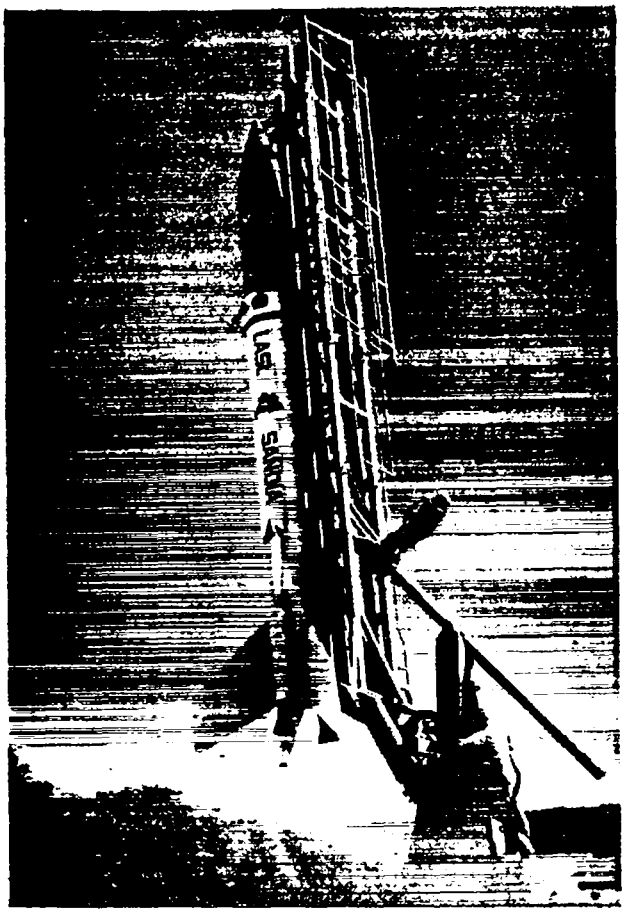


Fig. 4.

explosive-generator system reduced the power-supply weight to about 500 pounds and its volume to less than a cubic yard.

For many experiments, the explosive generator can be housed in a heavy-walled "containment vessel" that allows connection of the power pulse to *external* experiments but confines the shrapnel produced by the detonation. Although the explosive generator is lost for each test, all other components are protected. Such a facility could be used, for example, for proof-of-principle tests of several kinds of pulsed fusion concepts without having to make large initial investments for converters and capacitors for each test.

Other explosive flux-compression systems have produced the largest magnetic fields ever measured. Some systems produce magnetic fields over large volumes millions of times greater than the Earth's own field. The use of such systems has permitted studies of properties of materials of pure physical interest, of astrophysical significance, and of interest to the nuclear weapons program.

SUMMARY

High-energy pulsed-power systems slowly draw electrical power from some source, store the energy, and through one or more stages compress the energy in time, releasing a short high-energy burst. The use of explosive generators in the system can reduce both weight and volume while boosting the pulse energy by converting chemical explosive energy into electrical energy.

The potential cost-effectiveness should not be underestimated. For example, a pulsed-power system using only a converter and a fast capacitor bank can cost more than one dollar per joule of stored energy to install. On the other hand, for many types of experiments one could fabricate explosive generators to supply power for a number of pilot tests at substantially lower cost.

ACKNOWLEDGMENT

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Mini-Review readers are encouraged to correspond directly with the author.