PULSED POWER FROM EXPLOSIONS

Chemical energy can be converted directly to high power pulses of electricity or magnetism by explosive compression of magnetic fields

BY DIETRICK E. THOMSEN

Magnetic flux is a kind of intellectual hybrid, part mathematical construct, part physical reality. More than a century ago Michael Faraday introduced the custom of representing magnetic (and electric) fields by field lines drawn in the space around a magnet or electric charge. The shape of the lines is derived from the mathematical equations describing the field, and the lines tell you which way the force will pull and how strong it will be. Many schoolchildren will have seen the traditional demonstration in which iron filings are sprinkled on a glass plate over a bar magnet to visualize the flux lines.

Yet these field lines, this magnetic flux, has a palpable physical quality. If you push on it, it pushes back. Magnetic field lines do not readily pass through electrical conductors. If a field is surrounded with electrical conductors, the flux will be trapped. If this arrangement is then compressed, the trapped flux is compressed. Squeezing the flux increases the field strength, and the magnetic forces in the center of the volume become stronger and stronger.

Flux compression by mechanical means can produce momentarily magnetic fields that are far stronger than those that can be made by usual electromagnetic methods, and the technique has been used for years to produce ultrahigh magnetic fields for studies of the magnetic behavior of solids and thermonuclear plasmas. Now researchers in various countries (the United States, the Soviet Union and France are known to have programs) are developing the technique for use in a number of applications in scientific research and technology, where repeated high-power pulses are desired. Weapons simulation (the faking of radiation effects) is one application American researchers in the field acknowledge. Some observers have suggested that actual weapons using high powered pulses of electrons or ions generated through flux compression techniques might be possible, but people actually working in the field maintain silence on such possibilities.

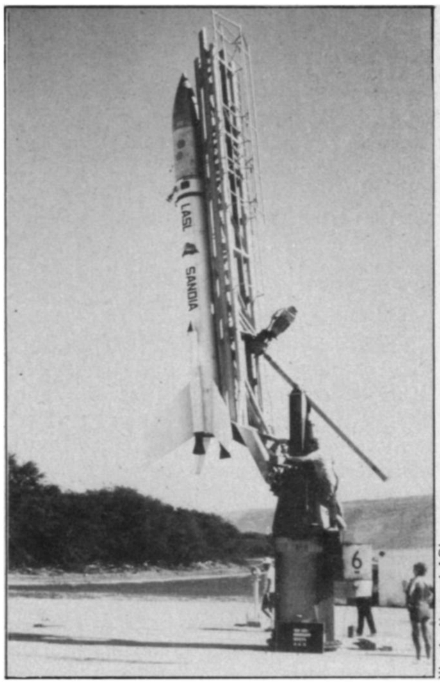
One of the things that hindered the development of this technique is that the flux compression has to be done explosively—or, rather, implosively. A real electromagnet—take a cylindric shape for illustration—does not entirely surround its flux lines. At some point there has to be a gap, the feed slot, between the leads that bring the electric current in and out. The gap is necessary to get magnetic flux inside the cylinder. A completely closed electrical conductor would keep flux out of its interior.

But if one tries to compress the cylinder slowly, the magnetic flux will slide out through the feed slot. The way to do it is to compress the cylinder fast so that the feed slot is blocked off while there is still some flux in the cylinder to crush together. The way to do *this* is to pack explosives around the cylinder and detonate them, imploding the cylinder. The procedure has two drawbacks: Shielding is necessary to protect the external world from blast and heat, and the magnet and everything inside it is destroyed by the shot. In fact, many of the high-magnetic-field experiments that have been done have been one-shot affairs.

Now, however, the thing can be done in a way that gets the compressed flux away from the explosion area. The arrangement uses a magnet with a rectangular rather than a circular cross section. Two opposite sides of the rectangle can be made to move in under the influence of the explosive charges. An escape slit for the flux is deliberately provided. The escape slit leads the flux to the interior of a cylinder, the load coil, which has a much smaller cross-sectional area than the rectangular magnet. Thus, a very large concentration of flux can be built up in the load coil. The load coil can be tapped for whatever use is desired. Although the explosive generator is still lost for each test, in this configuration the explosions can be kept in a shielded chamber, while the power is used outside it. All in all, it's a method for the repeatable conversion of the chemical energy released in the explosions directly to magnetic (and, if desired, electric) energy in very high power pulses.

There are many applications for this sort of device, but it has an historical as well as present connection with the type of controlled thermonuclear fusion device known as theta pinch. In the United States the Los Alamos Scientific Laboratory at Los Alamos, N.M., has made something of a specialty of theta pinches, and it is there and at Sandia Laboratories in Albuquerque that Amer-

Continued on page 284



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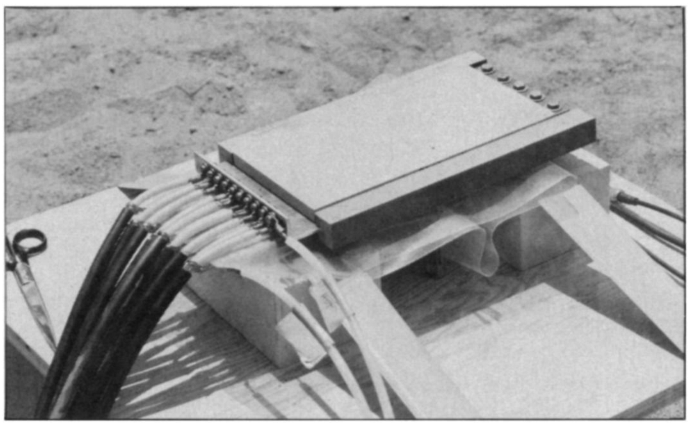


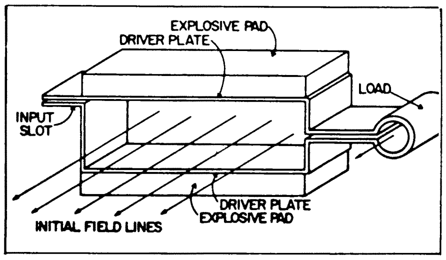
Pulsed power devices like the one shown at left (in this case powered by explosives only from the top) can be carried aloft by rockets like the one above.

ican research in these pulsed power devices is concentrated.

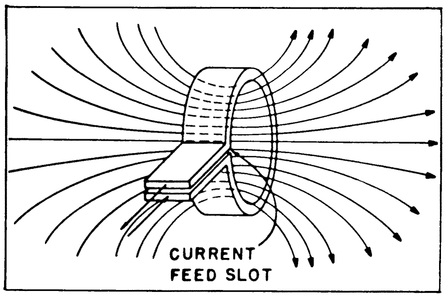
A theta pinch is a device in which the plasma that one hopes to make thermonuclear is held by a magnetic field inside a vacuum vessel that is either cylindrical or toroidal in shape. The attempt to bring the plasma to the temperature and density required for thermonuclear fusion is made by pinching the plasma together toward the axis of the vessel. A sudden increase in the magnetic field tends to pinch the plasma. This can be accomplished by pusling the electric power that generates the field or by imploding the liner of the vacuum chamber, which tends to pinch the plasma and increase the field strength at the same time. Such "imploding liner" fusion experiments go back a couple of decades, and the work on explosive power generators using compression of magnetic fields is a kind of spin-off from them. According to C. M. Fowler, who leads the explosive power generator work at Los Alamos (R. S. Caird, W. B. Garn, D. J. Erickson and B. L. Freeman are also involved), one of the major applications of the devices is proof-of-principle tests in theta-pinch studies. They are used to see if proposed theta-pinch arrangements will generate the conditions that it says on paper they will generate.

A great advantage of explosive devices over other ways of making power pulses is smallness of size and lightness of weight. The usual way of making power pulses is to use capacitors, which build up electric charges as a steady current is applied and then discharge all in a burst. The capacitors in household appliances are generally tiny objects, but those used, for example, to power electron guns used in advanced scientific and technological work can fill large rooms and must often use heavy oil instead of air as a dielectric because of the high charge they have to sustain. The explosive power devices can replace these capacitor banks with something much more portable.

The portability is exemplified by experiments in which the explosive pulsed power devices have been flown in rockets to inject plasma into the earth's magnetosphere to study how charged particles behave in the magnetic field. In this case the pulsed power device is used to power the gun that generates the plasma. According to Fowler, a conventional power supply for this plasma gun could weigh 9 or 10 tons and have a volume of several cubic yards. "The rocket experiments were possible because the explosive-generator system reduced the power-supply weight to about 500 pounds and its volume to less than a cubic yard." Such plasma guns have many other uses, some peaceful, some not so peaceful. One that Fowler cites is weapons simulation—that is, irradiating things in the ways weapons might to see what damage it does. Whether plasma guns powered in this way could be used



A typical cylindrical magnet (below) has magnetic flux inside the cylinder. A pulsed-power device is more practical in a rectangular cross section (above).



as actual weapons is something Fowler will not comment on, but there has been a certain amount of speculation and argument in various publications in recent months.

It has been suggested that such a gun might produce a plasma beam capable of shooting down incoming missiles. This speculation was not done abstractly but in connection with the discovery by intelligence agencies of an unusual installation at Semipalatinsk in Siberia (SN: 5/21/77, p. 329), which has characteristics that lead some people to suggest that it might be a giant pulsed power device of some kind. One of its features is a heavy steel chamber that looks as if it might be a place to detonate explosions. The Semipalatinsk installation was brought to public attention by Maj. Gen. George J. Keegan, retired head of Air Force intelligence, and its existence and possible significance were injected into the debate over the B-1 bomber and the cruise missile.

Objectors to the hypothesis of the high-power plasma gun weapon say that it is hard to imagine means of this kind producing a plasma beam powerful enough to punch its way through the atmosphere. In rebuttal there are those who suggest that such a thing might be useful in orbit to shoot from satellite to satellite. And one can go on and speculate from there.

Whatever the purpose of the Semipalatinsk facility may be, work on explosive pulsed power devices is under way in the Soviet Union. It is even speculated that the Soviets have used nuclear explosives as well as chemical ones in this kind of work. Andrei Sakharov, whose past connection with the Soviet Union's work on nuclear explosives is well known, has suggested using a nuclear driven flux compression device to power accelerators for particle physics experiments. Accelerators do take power in surges, and at the very high energies that Sakharov was talking about (1,000 billion electron-volts and higher) there might be some advantage as far as the lifetime of the accelerator's components is concerned. What might be done with a plasma gun powered by a nuclear driven flux compression device is something that scientists and weapons specialists can and will argue.

More immediate and certain, because available with the American chemically driven flux compression generators, and scientifically very important in Fowler's view, is the use of plasma guns in neutron radiography. It is the best way to provide neutron beams to probe the interiors of materials under test. Neutron radiography is similar to X-ray photography, but neutrons find out characteristics of the interior of the test sample that X-rays do not. The plasma gun can also be used to make X-rays or gamma rays for their varieties of radiography.

The extremely high magnetic fields themselves (up to 10 or 15 million gauss) are also experimentally useful. The behavior of matter in high magnetic fields is important in astrophysics and solid state physics among other departments of science. In solid state physics, knowledge of magnetic behavior could someday have technological use.

Fowler cites two such experiments in particular. In one, the spectrum of gallium selenide was studied at a temperature of 6° or 7° Kelvin and at fields of up to 2 million gauss. At this temperature the gallium selenide spectrum looks like a hydrogen spectrum. In fact, it seems to be what the hydrogen spectrum would look like at a billion gauss. The behavior of hydrogen in such strong magnetic fields is astrophysically important because such fields exist in condensed stars such as white dwarfs, and hydrogen is an important constituent of such stars.

A more solid-state type of investigation deals with the magnetic behavior of manganese fluoride. At low temperatures manganese fluoride is an antiferromagnet, but when it is chilled as low as liquid helium temperature (about 4°K), it reverts to a paramagnetic state in a field of about a million gauss. Experimentally one wants to find the relationship between field strength and temperature at which this transition occurs. It turns out that the higher the temperature, the less magnetic field it takes to make the transition happen.

All in all, Fowler believes that explosively driven flux compression generators are useful for a wide variety of scientific applications. And they have a potential for saving money. Fowler writes, "... 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." □