310-10 SR
FIP8502 OR 3,564,305

United States Patent

[11] 3,564,305

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[21] Appl. No. **445,495**
[22] Filed **Apr. 5, 1965**
[45] Patented **Feb. 16, 1971**
[73] Assignee **By mesne assignments, to**
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El Monte, Calif.
Continuation-in-part of application Ser. No. 390,408, Aug. 18, 1964, now abandoned.

[54] **METHOD AND APPARATUS FOR CREATING PULSED MAGNETIC FIELD IN A LARGE VOLUME**
6 Claims, 3 Drawing Figs.

[52] **U.S. Cl.** **310/10;** 307/106; 336/180
[51] **Int. Cl.** **H02k**
[50] **Field of Search** ..... 328/1; 336/180—186, 223, 225, 229; 310/10, 11; 307/106

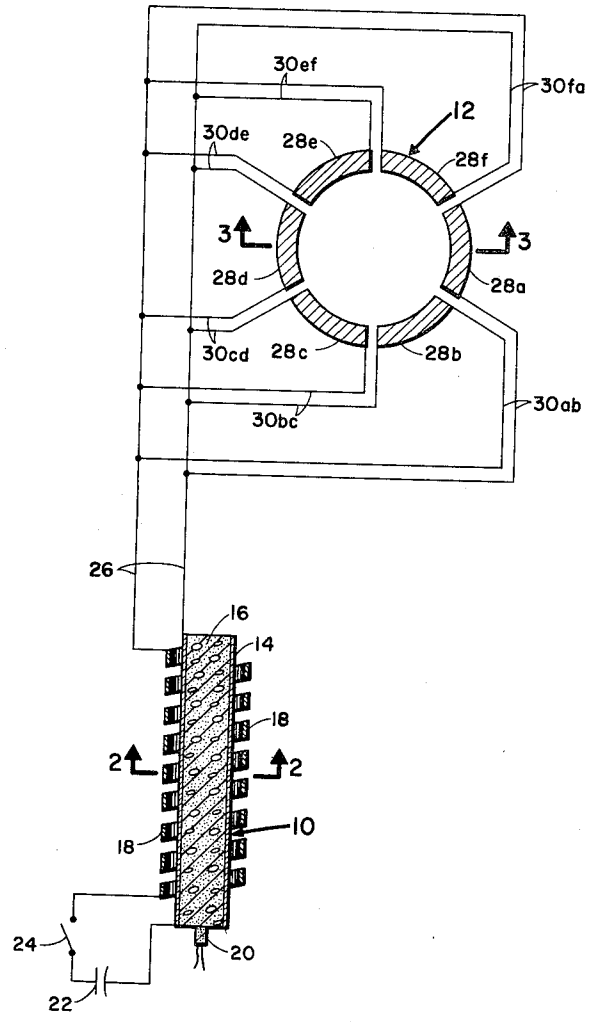
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ABSTRACT: This disclosure concerns a method and apparatus for creating a pulsed magnetic field in a large volume wherein the pulsed magnetic field may simulate the electromagnetic pulse effects produced by a nuclear detonation. The apparatus comprises an explosive generator disposed in an electrical circuit which includes a segmental inductive loop having a plurality of individual loop segments. The individual loop segments are respectively connected in series in the electrical circuit with the explosive generator and in parallel with respect to each other. The explosive generator includes an explosive charge mounted in a cylindrical armature which is surrounded by helical inductor coil. Upon discharging a pulse of electrical current through the inductor coil and detonating the explosive charge at one end of the armature, the armature is expanded so as to progressively contact the surrounding inductor coil along the length thereof. Thus, the electrical circuit is progressively short circuited, and the trapped magnetic flux is compressed. The trapped magnetic flux is then transferred by the explosive generator into the individual loop segments of the inductive loop with a corresponding increase in current and energy thereby establishing a pulsed magnetic field within the loop volume which is sufficiently large to simulate the electromagnetic pulse effects of a nuclear detonation.



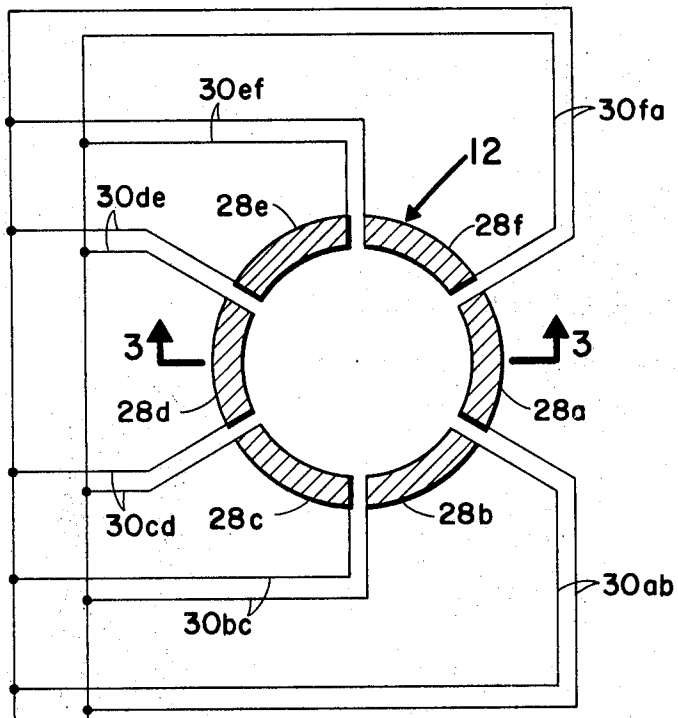
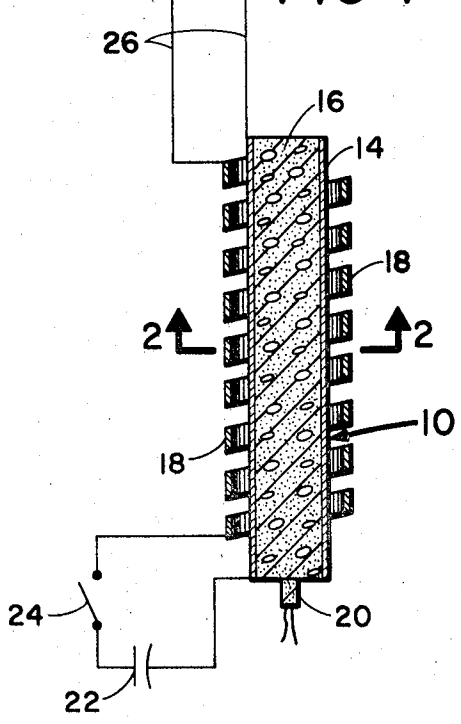


FIG 1



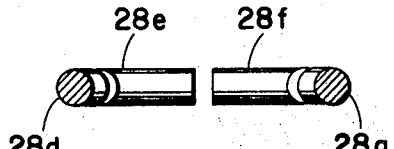


FIG 3

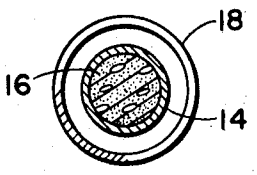


FIG 2

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METHOD AND APPARATUS FOR CREATING PULSED MAGNETIC FIELD IN A LARGE VOLUME

This is a continuation-in-part of my copending application, Ser. No. 390,409,filed Aug. 18, 1964, now abandoned.

This invention generally relates to an explosive generator system and more particularly to a novel low-inductance segmented load for coupling to an explosive generator and to a novel method of providing a pulsed magnetic field in a large volume.

An explosive generator is a device in which electrical energy provided by a small auxiliary energy source is multiplied by the direct conversion of high explosive energy to electrical energy. This conversion results from the extremely rapid deformation of the electrical circuit acted upon by the explosive. Typically, a high explosive inside a central tubular conductor, called the armature, is detonated at one end. The armature then expands in the form of a cone behind the moving detonation front. The expanding armature contacts an outer inductor such as a helix, thereby progressively short-circuiting the circuit, reducing the inductance, and compressing the trapped magnetic flux. This continues to the end of the generator when all of the trapped magnetic flux (neglecting losses) is transferred into a load with a corresponding increase in current and energy.

One potential use of an explosive generator is to drive an electrical current through a large loop or coil to create a pulsed magnetic field within a large volume. Of particular interest is the simulation of the near or induction magnetic field produced by a nuclear detonation. This primarily horizontal field, resulting from the vertical currents associated with the detonation near the earth is considered to be the principal effect of the nuclear detonation. The hazard to exposed equipment lies in the voltages and currents which this changing magnetic field induces in closed loops. If small, these pulses may couple into circuits and cause malfunction, while if large, components may be burned out thus disabling the equipment. In the absence of atmospheric nuclear testing to test directly the susceptibility of equipment to these nuclear electromagnetic pulses, it is necessary that suitable simulation testing devices be developed.

The multiplication or gain resulting from usual explosive generators has been found, however, to be limited by the ratio of the initial circuit inductance to the inductance of the load. Since the explosive generator has a low inductance, it is only useful operating into loads of still lower inductance. Large loops, on the other hand, typically have a high inductance in the range of 10^{-6} to 10^{-3} henries, comparable to that of the highest inductance explosive generator. A range of 10^{-9} to 10^{-7} is required for useful operation of the explosive generator. Thus, the major obstacle of using an explosive generator is this manner is the high inductance of a single large loop.

It is therefore an object of this invention to provide a novel means for and an improved method of coupling an explosive generator to an inductive load resulting in a high system gain.

Another object of this invention is to provide a novel inductive load for coupling an explosive generator.

Yet another object of this invention is to provide a novel means for providing a pulsed magnetic field in a large volume wherein an explosive generator is coupled to a segmented inductive loop resulting in a high energy gain.

In its principal aspect, the present invention comprises an inductive loop having a plurality of electrically parallel segments connected in electrical series with an explosive generator. The electrical current forced through the segmented loop by the explosive generator will establish a pulsed magnetic field within the loop volume which, if sufficiently large, will simulate the electromagnetic pulse effects of a nuclear detonation.

These and other objects, advantages, and features of the present invention will be apparent to those skilled in the art from the following description taken together with the appended drawings, wherein:

FIG. 1 is a diagrammatic view of an electrical circuit comprising an explosive generator system in accordance with the present invention, certain components of the circuit being shown in cross section for purposes of clarity;

FIG. 2 is a transverse cross-sectional view of an explosive generator forming one of the components of the electrical circuit shown in FIG. 1 and taken along line 2–2 of FIG. 1; and

FIG. 3 is a transverse cross-sectional view of a segmented inductor forming another component of the electrical circuit shown in FIG. 1 and taken along line 3–3 of FIG. 1.

The explosive generator system of FIG. 1 generally comprises an explosive generator **10** coupled in electrical series to a segmented inductive load **12**. The explosive generator **10** comprises a cylindrical conductor armature **14** which is filled with a high energy explosive **16**, the cylindrical armature **14** being concentrically arranged within a helical inductor **18**. A detonator **20** is provided at one end of the high energy explosive **16**. A small electrical energy source **22**, such as a capacitor bank, and an electrical switch **24** are connected in electrical series with the detonator end of the armature **14** and inductor **18**. Electrical leads **26** extend from the other end of the armature **14** and inductor **18** for series electrical connection to the load **12**. It will be understood that other suitable explosive generators may be used within the spirit of this invention, such as, for example, any of the explosive generators which are disclosed in copending U.S. application, Ser. No. 324, 133, filed Nov. 15, 1963, now U.S. Pat. No. 3,356,869 issued Dec. 5, 1967.

Operation of the explosive generator **10** is initiated by closing the switch **24** which permits the capacitor **22** to discharge through the inductor **18**. The high energy explosive **16** is then ignited by means of the detonator **20**, thus expanding the armature **14** in the form of a cone behind the moving detonation front. Detonation of the explosive **16** is timed so that the leading edge of the armature **14** will contact the leading edge of the inductor **18** when the current wave from the capacitor **22** is at its maximum. This initial contact of the expanding armature **14** and the inductor **18** removes the capacitor **22** and switch **24** from the initial electrical circuit. As the expansion of the armature **14** continues, its point of contact with the helical inductor **18** travels around the inside of the helix, progressively and continuously shorting out the winding, reducing the inductance, and compressing the trapped magnetic flux. This trapped magnetic flux (neglecting losses) is transferred into the load **12** with a substantial increase in current and energy from that supplied by the capacitor **22**.

To assist in understanding what is believed to be the theory of operation, the explosive generator circuit may be considered as having a resistance R and an inductance L which surrounds an initial magnetic flux Φ. Since the load **12** is connected in electrical series with the explosive generator **10**, its resistance, inductance and flux must be included in the circuit.

The sum of the voltages around this circuit may be written as:

$$\frac{d(LI)}{dt}+RI=0 \tag{1}$$

If it is assumed that neither L nor R is a constant, the following definition of inductance is invoked:

$$L(t)=\frac{\phi(t)}{I(t)} \tag{2}$$

This expression may be rewritten as:

$$\frac{d\phi(t)}{dt}+\frac{R(t)}{L(t)}\phi(t)=0 \tag{3}$$

The solution of this equation is:

$$\phi(t)=\phi_o e^{-\int_o^t [R(t)/L(t)]dt} \tag{4}$$

Again, by using eq. (2), the expression for current may be written in the following form:

$$I(t)=I_o\left[\frac{L_o}{L(t)}\right]e^{-\int_o^t [R(t)/L(t)]dt} \tag{5}$$

where I_o = initial current L_o = initial inductance.

From equation (5) it can be seen that the current can be increased by reducing $L(t)$ in a time short compared to the circuit decay time $L(t)/R(t)$ which in general is changing during this time. Physically this is done by exploding the armature **14** with the high explosive **16**. The circuit energy which is stored in the magnetic field is:

$$W(t)=\frac{L(t)I(t)^2}{2} \quad (6)$$

The expression for current may be substituted and the equation rewritten in the form:

$$W(t)=W_o\frac{L_o}{L(t)}e^{-2\int_o^t[R(t)/L(t)]dt} \quad (7)$$

where $W_o=L_oI_o^2/2$. It is apparent that there can be a net gain in circuit energy if deformation of the circuit is done rapidly.

As can be seen from equations (5) and (7) the upper limit of both current and energy gain for the explosive generator **10** is the ratio of initial to final or load inductance L_o/L_f. This ratio must be in the range of 10^2 to 10^3 to provide reasonable power gain after normal electrical losses have taken their toll.

The inductance of a single circular loop of wire for use as the load of an explosive generator can be approximated by:

$$L=\mu_o r\left[1n\frac{8r}{a}-2\right]\text{henries} \quad (8)$$

where μ_o = permeability r = loop radius and a = wire radius.

A 20-m. radius loop with a conductor radius of 1 cm. would have an inductance of about 194 μ henries. It is apparent that because of this large inductance an extremely large generator would be required to obtain a substantial energy multiplication.

As shown in FIG. **1**, however, the present invention divides the loop **12** (the load for the explosive generator **10**) into a plurality of segments **28** *a—f*. The drawing illustrates the number of segments **28** as six although more or less may be desirable. Each segment **28** is connected in electrical parallel by means of low inductance, low loss transmission lines **30** *ab—fa*. The entire loop **12** is connected in electrical series to the explosive generator **10** by means of the electrical leads **26**. Coaxial cables, parallel-plate lines, or multipole wire lines are suitable to provide the transmission lines **30** and electrical leads **26**.

Considering the loop **12** divided in N number of segments, the inductance of the loop L_{loop} will be:

$$L_{loop}=\frac{\phi}{I} \quad (9)$$

where Φ is total number of flux linkages and
I is total current.

Each segment links Φ/N of the total flux; therefore

$$L_{Segment}=\frac{\phi}{IN} \quad (10)$$

When all the segments are placed in parallel, the inductance of the combination will be I/N that of a segment.

$$L_{Parallel}=\frac{L_{Segment}}{N}=\frac{\phi}{IN^2}=\frac{L_{loop}}{N^2} \quad (11)$$

Therefore the inductance of the loop **12** has been reduced by a factor of N^2 when compared to the single wire loop.

The inductance of the transmission lines **30** running to each segment **28** can be made as small as desired by using the appropriate number of cables in parallel.

If 30 drive points are used, the inductance of a 20-m. radius loop will be reduced from 194 μ henries to 0.21 μ henries. An explosive generator with an inductance of 1,000 μ henries using 100 lbs. of high explosive, can induce 10 M joules into the magnetic field of such a loop inductance.

Considering the parallel segment coupling method from a physical point of view, it can be seen that paralleling reduced the very high current from the generator (10 million amperes is typical of efficient generator performance) to the much smaller value appropriate to the required magnetic field. For example, if 100 gauss is desired at the center of a 20-m. radius loop, then the necessary current I is given by

$$I=\frac{2Ba}{\mu_o} \quad (12)$$

where B is the field in webers
μ_o = permeability = $4\pi\times10^{-7}$
I = 319,000 a. a number much smaller than 10^7 a.

The stored energy in the magnetic field from $E=\frac{1}{2}LI^2$, where L = 195μ henries, is found to be $E=10^7$ joules. In this manner it is possible to couple an explosive generator to a large loop to provide a pulse magnetic field in a large volume. Electromagnetic pulses with component frequencies in excess of 10 kilocycles per second can be achieved to simulate the induction effects of nuclear detonations.

While a specific embodiment of the invention has been illustrated and described, it is to be understood that this embodiment is by way of example only, and that the invention is not to be construed as being limited thereto, but only by the proper scope of the appended claims.

I claim:

1. A high gain explosive generator system comprising:
a. explosive generator means for establishing a pulsed electrical current; and
b. inductive load means connected to said generator means, said load means comprising a single inductor member divided into physically separated segments, each of said segments being connected in electrical series with said generator means but in electrical parallel with each other.

2. A high gain explosive generator system comprising:
a. explosive generator means for establishing a pulsed electrical current; and
b. inductive load means connected in series to said generator means, said load means comprising a single discontinuous inductive loop having a plurality of segments connected in electrical parallel with each other.

3. A method of simulating the electromagnetic effects of a nuclear detonation comprising:
a. enclosing a volume with a discontinuous inductive loop having a plurality of segments connected in electrical parallel; and
b. driving a pulsed electric current from an explosive generator through said loop segments to establish a pulsed magnetic field within the enclosed volume, each of said segments being connected in electrical series with the explosive generator.

4. A method of creating a pulsed magnetic field in a confined volume comprising:
a. discharging a pulsed electrical current through the inductor of an explosive generator comprising an explosive-containing armature and an inductor surrounding the armature;
b. detonating the explosive contained in the armature of the explosive generator in timed relation to the discharge of the pulsed electrical current through the inductor of the explosive generator such that successive expansion of the armature due to the detonation of the explosive contained therein causes progressive contact between the armature and the inductor of the explosive generator along the lengths thereof for compressing magnetic flux; and
c. directing the compressed magnetic flux having a substantial increase in current and energy from the pulsed electrical current through a segmented inductive loop having a plurality of individual loop segments respectively connected in series in an electrical circuit with the explosive generator and in parallel with respect to each other.

5. A high gain explosive generator system comprising:
a. an electrical circuit;
b. explosive generator means disposed in said electrical circuit for providing compressed magnetic flux upon actuation thereof by an explosion;
c. a segmented inductive loop disposed in said electrical circuit and having a plurality of individual loop segments respectively connected in series in the electrical circuit.

with said explosive generator means and in parallel with respect to each other;

d. means in said electrical circuit for discharging a pulsed electrical current through at least a portion of said explosive generator means; and

e. means operating in timed relation to the discharge of the pulsed electrical current to cause an explosion actuating said explosive generator means, whereby the compressed magnetic flux provided by the actuation of said explosive generator means is driven through said loop segments to establish a pulsed magnetic field within said segmented inductive loop.

6. A high gain explosive generator system comprising:

a. an electrical circuit;

b. an explosive generator disposed in said electrical circuit and comprising;

1. an armature containing an explosive therein;
2. inductor means surrounding said armature; and
3. detonator means in proximity to the explosive contained in said armature and actuatable for detonating the explosive;

c. said armature and said inductor means of said explosive generator being connected in series in said electrical circuit;

d. a segmented inductive loop disposed in said electrical circuit and having a plurality of individual loop segments respectively connected in series in the electrical circuit with said explosive generator and in parallel with respect to each other;

e. means in said electrical circuit for discharging a pulsed electrical current through said inductor means of said explosive generator; and

f. said detonator means being actuatable in timed relation to the discharge of the pulsed electrical current through said inductor means to detonate the explosive contained in said armature for successively expanding said armature to cause progressive contact between said armature and said inductor means of the explosive generator along the lengths thereof for compressing magnetic flux, whereby the compressed magnetic flux is driven through said loop segments to establish a pulsed magnetic field within said segmented inductive loop.