

April 19, 1960

E. P. CARTER
BLASTING MACHINE
Filed Feb. 4, 1955

2,933,653

FIG. 1.

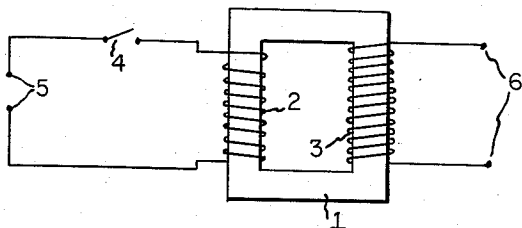


FIG. 2.

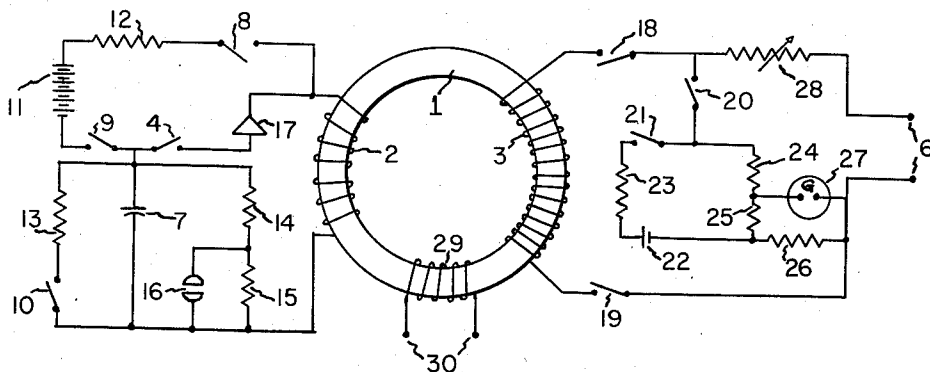


FIG. 3.

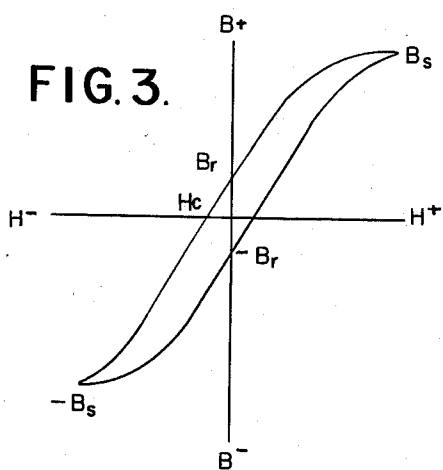
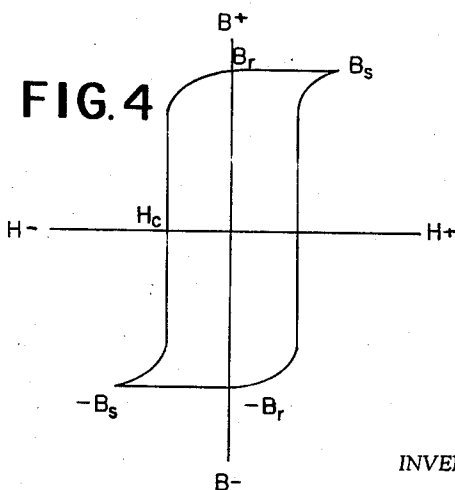


FIG. 4.



INVENTOR

Elbert P. Carter

BY

Thos. A. Wilson
ATTORNEY

1

2,933,653

BLASTING MACHINE

Elbert P. Carter, Wilmington, Del., assignor to E. I. du Pont de Nemours and Company, Wilmington, Del., a corporation of Delaware

Application February 4, 1955, Serial No. 486,137

3 Claims. (Cl. 317—80)

The present invention relates to an improved blasting machine. More particularly, this invention relates to a blasting machine adapted to provide a firing current of precisely known duration.

Explosive charges are frequently used to produce earth vibrations which can be measured and used to determine the structure of underlying earth formations. An essential feature of such measurement is an exact knowledge of the moment at which the explosive charge is detonated. Two main systems are used to provide the observer with the time of detonation of the explosive charge. In one system, a low firing current is employed to heat the bridge wire of the detonator, and the ignition charge functions before the bridge wire burns through, thus severing the bridge wire by the explosion. A record of the time at which the current was interrupted provides the observer with the required information regarding the detonation of the charge. In the other system, a firing current of at least 5 amperes is applied. With present day blasting caps, the firing current of this magnitude produces essentially an instantaneous detonation of the explosive charge, so that the only record required is the record of the application of the current.

In U.S. Patent 2,623,922 issued December 30, 1952 an apparatus which produces an easily recognizable firing pulse of short duration is described. In this apparatus, a condenser is discharged through a firing circuit which contains in parallel with the detonators a resistance adapted to reduce the charge on the condenser below a level at which detonators can be initiated within a few milliseconds. By the use of this apparatus, the operator is certain that the detonator is initiated by a pulse of short duration and can, therefore, fix with accuracy the time the explosive charge is initiated. The apparatus possesses the disadvantage that, in order to provide the energy required to initiate the detonator, a very high initial voltage must be applied to the firing circuit because of the rapid rate of discharge of the condenser in this type of circuit, and only a portion of the energy stored in the condenser is actually usable for initiation of the detonator.

In mining operations where flammability hazards exist, it is also desirable to limit the duration of the electrical energy supplied to the blasting circuit in order to avoid ignition of the flammable atmosphere which may be released from the formation as the result of the explosion of the blasting charge. The U.S. Bureau of Mines requires that a "permissible" blasting machine shall have an output voltage not greater than twelve volts at the end of a thirty millisecond period following the actuation of the firing circuit. Such performance has been achieved mechanically in generator-type blasting machines or electrically by means of a condenser discharge circuit containing a resistance shunt in the firing circuit. The existing generator-type machines depending on mechanical current control are of necessity bulky, of considerable weight, and their operation depends upon skillful operator control. The condenser-type machine, on the other

2

hand, possesses the same disadvantages previously described with regard to the seismograph blasting machine, i.e., high initial voltage and rapid loss of energy.

An object of the present invention is to provide a blasting machine which does not possess the aforementioned disadvantages. A further object is to provide a blasting machine which is compact, light weight, and capable of delivering a pulse of energy of uniform amplitude to a firing circuit for a predetermined period of time. Additional objects will become apparent as this invention is more fully described.

I have found that the foregoing object may be achieved when I provide a blasting machine comprising a saturable-core transformer having a primary and secondary coil, a source of direct current and a circuit closing switch in series with the primary coil, and a firing circuit in series with the secondary coil. Additional circuits and electrical elements will generally be included to increase safety, permit recording and facilitate operation. In order to more fully describe my invention, reference is now made to the accompanying drawings in which:

Figure 1 represents a basic circuit in accordance with the present invention;

Figure 2 represents a complete circuit for a safe blasting machine;

Figure 3 represents a B-H curve hysteresis loop for an ordinary saturable core; and

Figure 4 represents a B-H curve hysteresis loop for the preferred saturable core.

In Figure 1, 1 is a transformer core containing primary coil 2 and secondary coil 3. In series with primary coil 2 is a switch 4 and a source of direct current 5 (a generator, battery, capacitor, etc.). In series with the secondary coil are the firing circuit terminals 6.

In Figure 2, 1 represents a transformer core containing primary coil 2 and secondary coil 3. In series with primary coil 2 is a circuit containing a switch 4, a capacitor 7 and a selenium rectifier 17. Also in series with the primary coil 2 is a circuit containing capacitor 7, switches 8 and 9, battery 11, and resistance 12. In series with capacitor 7 is a circuit containing switch 10 and resistance 13. In parallel with capacitor 7 is an indicator containing resistances 14 and 15 and neon lamp 16, the latter being in parallel with resistance 15.

In series with secondary coil 3 are switches 18 and 19, variable resistance 28, and firing circuit terminals 6. In parallel to terminals 6 is a balancing circuit containing switches 20 and 21, battery 22, resistances 23, 24, 25, and 26, and galvanometer 27.

Transformer core 1 also contains a third coil 29 having recorder terminals 30.

In Figures 3 and 4, the vertical axis B represents the flux lines per square centimeter of core cross-section (gauss), and the horizontal axis H represents the magnetizing force in ampere turns per unit length of mean magnetic path in the core. B_s and $-B_s$ represent the points at which saturation flux density has been reached in a positive and a negative direction respectively. B_r and $-B_r$ represent the values of magnetic flux which the core will retain when a magnetizing force which produced saturation is removed.

The operation of the blasting machine of the present invention is as follows: When switch 4 is closed, completing a circuit from direct current source 5 through primary coil 2, a flux change is produced in core 1. This flux change induces an electromotive force in secondary coil 3 which can be applied to a load (one or more detonators) connected to the terminals 6. Continued current flow through primary coil 2 will produce continued flux change until core 1 becomes saturated, after which continued current flow will no longer produce

a flux change. The induction of an electromotive force in the secondary coil 3, therefore, ceases when the core 1 becomes saturated. The time period of current flow in this circuit containing secondary coil 3 is exactly equal to the time required to saturate core 1.

If the core 1 is of the usual material having a low hysteresis, such as indicated by the B-H curve in Figure 3, the change in flux would be represented by a line from the intersection of axis B and axis H to B_s if the core 1 had not been previously magnetized. If the core 1 had been previously magnetized by a current flowing in the same direction as the presently applied current, the change in flux would be represented by a line from B_r to B_s . If the core 1 had been previously magnetized by a current flowing in the opposite direction to the presently applied current, the change in flux would be represented by a line from $-B_r$ to B_s .

Neglecting the circuit resistances, the changing flux produced by the electromotive force applied to the primary coil 2 will generate an electromotive force in secondary coil 3. This induced electromotive force is related to the flux change by the following equation:

$$\text{EMF (volts)} = N \frac{\Delta\phi}{\Delta t} \times 10^{-8} \quad (1)$$

wherein:

N = the number of turns in the coil

$\Delta\phi$ = the change in flux (Maxwells)

Δt = the time in seconds over which the change takes place

(1 volt is equal to 10^8 Maxwells per second per turn)

In order to produce this change of flux in core 1, magnetizing current must flow through primary coil 2 to produce a magnetomotive force in the core in excess of H_c . A second component of primary current is required to make up for eddy current losses in the core. These losses depend on the rate at which the flux change $\Delta\phi$, takes place. In practical cases, the primary ampere turns required for eddy current losses are of the order of the magnetizing currents or less. When a load is connected across the secondary coil 3, so that a secondary current flows, a third component of current must flow in primary coil 2, of magnitude such that the additional primary ampere turns are just equal to the secondary ampere turns. If the source of E.M.F. in Equation 1 can supply these three components of primary current without an attendant reduction, the switching time or power transfer time, will be essentially independent of the load on the secondary. In any case the effective E.M.F. for Equation 1 is the instantaneous voltage measured across the terminals of the primary coil 2 less the voltage drop across the D.C. resistance of the primary coil 2 caused by the sum of the three primary current components. If a transformer is desired which will deliver 500 volts direct current for 0.25 milliseconds, and a core, 1 square inch in cross-section having a saturation flux density of 40,000 Maxwells per square inch is available (assuming for this example that the residual flux in the core is zero: i.e., $-B_r = B_r = 0$) by application of Equation 1, 312.5 turns for the secondary coil are required. If the effective primary coil E.M.F. available from the source is 100 volts, by applying same equation, 62.5 turns for the primary coil are required. When a core having a known residual flux value (B_r or $-B_r$) is to be used, this value must be first subtracted or added to the saturation flux value to determine the change in flux which will occur.

Thus, in Figures 1 and 3, the basic arrangements and usual core materials have been depicted, and an operative blasting machine can be prepared utilizing nothing more. However, to insure successful detonation of a blasting cap, sufficient current must be provided to heat the bridge wire to incandescence. The resistance of the

cap itself and the circuit resistance are unavoidable. Therefore, the source of electrical energy must be capable of supplying the required power within the desired period. This requirement would necessitate a very large battery or generator, and in the case of the generator, mechanical devices to prevent energizing the circuit before the generator reached the desired output level. For the foregoing reason, I prefer to include a capacitor in the assembly to act as the source of energy for the primary coil. The capacitor may be charged from either a battery or a direct current generator.

For safety reasons, I prefer to use a transformer whose core material has a rectangular hysteresis loop of B-H curve such as shown in Figure 4. As can be seen in Figure 4, B_r lies very near to the saturation point. Thus, if it is desired to traverse the curve from $-B_r$ to B_r , the core must first be driven or reset to $-B_r$. Thereafter, once energy has been passed through the core, no more pulses of the same polarity can be passed through until the core has been deliberately reset again to $-B_r$. This prevents accidental direct application of power to the output terminals until the core has been reset.

Figure 2 represents, therefore, a preferred embodiment of this invention in which safety features have been introduced. In this embodiment, switch 10 is closed and all other switches are open when the assembly is not actually being used. The closing of switch 10 insures that no charge can remain in capacitor 7. When the assembly is to be used, the detonator or detonators are connected across terminals 6 and the capacitor 7 is charged by opening switch 10 and closing switches 8, and 9. In charging the condenser 7, the current from battery 11 flows through the primary 2, thus resetting core 1 to its negative hysteresis point $-B_r$. The resistance 12 restricts the current to a value below that at which sufficient current to fire an initiator would be induced in the secondary coil 3 to prevent accidental initiation even if switches 18 and 19 were closed or if the detonator were improperly connected. To enable the operator to ascertain when capacitor 7 is sufficiently charged, an indicator circuit including resistance 14 and 15, and a neon lamp 16 is connected in parallel with the capacitor 7.

In order to fire detonators connected at terminals 6, switches 18 and 19 are closed, switches 8 and 9 are opened, switch 10 remains open, and switch 4 is closed. The capacitor 7 is thus discharged through the selenium rectifier 17 and primary coil 2. The applied electromotive force changes the flux density in transformer core 1 from negative residual flux value, $-B_r$, to positive saturation, B_s . At the end of the discharge the induced flux value relaxes from B_s to the positive residual flux value, B_r . This change in flux induces the desired electromotive force in secondary coil 3 to fire the detonators connected at terminals 6. The rectifier 17 prevents reverse current from flowing at the end of the discharge, thus effectively stopping energy transfer through the transformer, and keeping the core flux at the positive residual value B_r . To permit accurate recording of the firing pulse, a third coil 29 is connected at terminals 30 to a recording instrument. The change in flux in core 1 induces a recording current in coil 29 simultaneously with the induction of the firing current in secondary coil 3.

In seismograph shooting, it is desirable that the current applied to the detonator be constant in each case. Therefore, a variable resistance 28 is included in the firing circuit. This resistance is set at a proper value by balancing the resistance of the firing circuit against a known resistance. For this purpose a balancing circuit is employed including a low-voltage battery 22, a resistance 23, a switch 21, resistances 24, 25, 26, and a galvanometer 27 connected across the firing circuit through switch 20. With switches 18 and 19 open, switches 20 and 21 are closed. Switches 20 and 21, preferably combined in a single push button switch, are

5

then closed and any deflection of galvanometer 27 noted. Variable resistance 28 is then adjusted until the total resistance of the firing circuit, including resistance 28, is equal to the total resistance of the balancing circuit, at which point no deflection of the galvanometer 27 will occur. The balancing circuit is entirely disconnected from the firing circuit during operation of the assembly.

Preferably the switches are operated by a three-position cam-operated rotary power control switch arranged to return to the off position whenever the handle is released. At the off position, switch 10 is closed, all other switches are open. At the next position in the sequence, switch 10 is opened, switches 8 and 9 are closed, and switches 18 and 19 remain open. In the final sequence, switches 4, 18, and 19 are closed and switches 8, 9, and 10 are open. Preferably, switches 18 and 19 will close a short interval before switch 4.

As previously mention, I prefer to use a transformer having core material of the rectangular-hysteresis loop type as shown in Figure 4, with a high value of residual flux or induction. In addition, the saturation flux density is very little greater than the corresponding residual flux density in these materials. A detailed description of such core material and its characteristics may be found in an article entitled "Static Magnetic Storage and Delay Line" by An Wong and Way Dong Woo published in volume 21 (January 1950) of the Journal of Applied Physics.

A blasting machine designed for use in seismic exploration will have a transformer core of such cross-section and a primary coil of such number of turns that saturation will occur in less than 0.5 millisecond. The electromotive force source will have a capacity sufficient to provide the energy needed to initiate the detonators customarily used. Similarly, a blasting machine designed for use as a permissible machine will have the necessary construction and electrical elements. The requirements are simple to fulfill by the assembly of the present invention without the need for experimentation.

The invention has been fully described in the fore-

6

going. Many variations and modifications will occur to one skilled in the art which fall within the scope of this invention. I intend, therefore, to be limited only by the following claims.

I claim:

1. A blasting machine comprising a "rectangular hysteresis loop" saturable-core transformer having a primary and a secondary coil, a source of direct current and a circuit-closing switch in series with the said primary coil for applying a current in one direction, a source of direct current and a circuit-closing switch in series with the said primary coil for applying a current in the opposite direction, and a firing circuit in series with said secondary coil.

2. A blasting machine as claimed in claim 1, wherein the source of direct current comprises a capacitor connected in series with a circuit-closing switch and a current producing means.

3. A blasting machine comprising a saturable core transformer having a primary and secondary coil, a pulse circuit containing a circuit-closing switch and a capacitor in series with said primary coil, a safety short circuit containing a circuit-opening switch and a resistance in series with said capacitor, a charging circuit containing a source of direct current and a pair of circuit-closing switches in series with said capacitor, and a detonator firing circuit and a pair of circuit closing switches in series with said secondary coil.

References Cited in the file of this patent

UNITED STATES PATENTS

1,728,003	Nickle	Sept. 10, 1929
2,003,483	Frye	June 4, 1935
2,047,431	Randolph	July 14, 1936
2,246,178	Levoy	June 17, 1941
2,446,671	Short	Aug. 10, 1948
2,546,686	Bickel	Mar. 27, 1951
2,617,851	Birch	Nov. 11, 1952
2,623,922	Muffly	Dec. 30, 1952
2,685,653	Orr	Aug. 3, 1954