CAPACITOR DISCHARGE TYPE BLASTING MACHINES

Inventors: Frank J. Digney, Jr., 1 Long Pound Road, Hewitt, N.J. 07421; Earl M. Phinney, 10 Ceperly Avenue, Oneonta, N.Y. 13820

Filed: Dec. 30, 1971
Appl. No.: 214,187

U.S. Cl. .................... 317/80, 102/70.2, 307/106, 315/183, 320/1
Int. Cl. .............................. F23g 7/02
Field of Search .................. 317/79, 80, 96; 307/106; 102/70.2; 315/206, 183; 320/1; 321/2; 323/77

References Cited
UNITED STATES PATENTS
3,417,306 12/1968 Knak ................ 320/1
3,502,024 3/1970 Mountjoy .......... 102/70.2
3,584,929 6/1971 Schuette............... 315/244
3,603,844 9/1971 Fritz .................. 317/80

Primary Examiner—Volodymyr Y. Mayewsky
Attorney—James J. Flynn

ABSTRACT

Capacitor discharge blasting machines for initiating electro-explosive devices, e.g., electric blasting caps which comprises in combination, means for supplying direct current at a controlled rate and at potentials above 1,500 volts, a non-electrolytic capacitor capable of accumulating charges at potentials in excess of 1,500 volts and capable of withstanding repeated charge-discharge cycles, means for indicating that such capacitors are being charged, electronic firing switch and interlock means positioned between and communicating with said capacitor, and electronic firing switch means for delivering current from said capacitor to current output terminals and thence to an electric blasting cap firing circuit, and means for bleeding off unwanted or residual charges from the power supply and current-discharging means.

11 Claims, 3 Drawing Figures
CAPACITOR DISCHARGE TYPE BLASTING MACHINES

BACKGROUND OF THE INVENTION

This invention relates to blasting machines, i.e., apparatus used for initiating electro-explosive devices including commercial electric blasting caps, and more particularly to capacitor discharge type blasting machines, and to a method for blasting using such machines to initiate explosive charges.

The use of blasting machines to initiate large blasting rounds, in preference to direct use of commercial power lines as the source of electric current, is well recognized, especially for underground blasting operations that employ delay electric blasting caps. Employment of capacitor discharge type blasting machines to initiate electric blasting caps, including both instantaneous and delay electric blasting caps, is especially well known, and some capacitor discharge blasting machines have been provided that initiate relatively large numbers of electric blasting caps in a single blasting round. The number of electric blasting caps that can be initiated in a single round by a given blasting machine depends in part on the way in which the electric blasting caps are connected to the blasting machine. In spite of the fact that larger numbers of electric blasting caps can be initiated from a given current source in a single blast by arranging the caps in series or in parallel series circuits, as is well known in the blasting art, the relative simplicity of making parallel firing circuit hookups and the greater certainty of including in the firing circuit all of the caps in the round have created demands for dependable means of firing even larger numbers than heretofore of electric blasting caps that are connected in parallel firing circuits.

Field experience has shown that capacitor-discharge blasting machines often do not perform up to their nominal cap-firing ratings because the ratings are established under arbitrary and favorable test conditions that are not representative of field conditions. As a result, blasters often experience missed holes if the capacitor discharge blasting machines are used near their rated electric blasting cap-firing capacity in otherwise well designed and executed blasting rounds. Furthermore, the blasting machines often are stored and used under favorable corrosive environmental conditions such as high temperature, high relative humidity, exposure to dripping water that is corrosive in nature, and exposure to corrosive mine atmospheres. As a result, the electrical components of the blasting machines deteriorate so that the machines no longer deliver to all the caps the expected cap-firing energy, and highly dangerous missed holes result. There has been a need for condenser-discharge blasting machines that are capable of initiating dependably and simultaneously even larger numbers of electric blasting caps than heretofore known, particularly when connected in a parallel firing circuit; that discharge to the firing circuit only when adequate energy is available to initiate that all caps in the circuit will be initiated; that can be powered from conventional or rechargeable wet or dry cells or from a conventional 110 V or other lighting circuit; that are simple to operate, rugged and light in weight, one which will function repeatedly and dependably over a large number of firings without deterioration of critical electrical components and one in which connecting lines from blasting machine to the cap circuit are minimized in length, while control of the machine can be exercised from a remote location so removed from the immediate area of the blast that operating personnel are not exposed to damaging effects thereof. The blasting machines of the present invention fulfill such needs and provide an improved capacitor discharge blasting machine that will dependably and repeatedly deliver an adequate firing current within an effective time interval so as to ensure firing of all electric blasting caps within the designated nominal cap-firing capacity of such machines.

SUMMARY OF THE INVENTION

The improved condenser discharge blasting machines used for initiating electro-explosive devices comprise, in combination, (a) a non-electrolytic main storage capacitor, including means for charging said capacitor to a potential in excess of 1,500 volts, said capacitor being capable of discharging currents in excess of 1,000 amperes, one side of said capacitor being connected directly to one of two energy-output terminals, (b) an electronic firing switch as the sole means of circuit closure connecting the other side of said main storage capacitor to the second energy-output terminal, (c) means for insuring that said electronic firing switch will discharge the main storage capacitor at a prescribed minimum voltage in excess of 1,500 volts, (d) means for connecting said energy-output terminals to a circuit containing an electro-explosive device, and (e) means for disarming the main storage capacitor.

The main storage capacitor can be charged by any suitable means, for example, a hand-cranked alternator and rectifier circuit, a 110–440 volt AC power line connected through a normally open circuit closure control to the primary of a step-up transformer, the secondary of which is connected to the main storage capacitor through a rectifier circuit, or a battery connected to an oscillator circuit through a normally open circuit closure control that supplies alternating current to the primary of a step-up transformer, the secondary of which is connected to the main storage capacitor through a rectifier circuit.

The interlock means or means for insuring that the electronic switch will discharge the capacitor at a minimum voltage in excess of 1,500 volts is a vital feature of this invention.

The electronic firing switch comprises either a two-element spaced arc gap or a triggerable three-element spaced arc gap enclosed within a casing containing an ionizable gas. Preferably, the electronic firing switch has a main untriggered gap breakdown voltage which is substantially higher than the prescribed blasting machine firing voltage, and which can be triggered to fire with a main gap voltage substantially below the prescribed firing voltage, the input of said three-element arc gap being connected to one terminal of the main storage capacitor and the output of said three-element arc gap being connected to the first of two energy-output terminals and the other side of the main storage capacitor being connected directly to the second energy-output terminal, said electronic firing switch cooperating with (a) a pulse triggering transformer the secondary of which is connected in series with a resistor between the input to the three-element
arc gap and the triggering element of said three-element arc gap; (b) a pulse-shaping circuit comprising a resistor and capacitor in parallel, said pulse-shaping circuit connected in series with the primary of the pulse-triggering transformer and a two-element arc gap which series circuit is connected parallel to the main storage capacitor, said two-element arc gap having a gap spacing that insures conduction automatically when the main storage capacitor reaches the prescribed firing voltage thereby generating a trigger signal of suitable polarity and strength that renders the three-element arc gap conductive.

From the above it can be seen that one side of the main storage capacitor is connected directly to one of two energy-output firing terminals while the other side is connected to the other energy-output terminal through a hermetically sealed, long-lived, electronic firing switch and circuit of either the type that automatically fires at a prescribed machine firing voltage of that fires only when triggered either automatically at the prescribed machine firing voltage range or manually at or above the prescribed minimum machine firing voltage. The apparatus has a terminal shunt resistance whose value is selected in light of the value of the main storage capacitor so as to provide a discharge time constant adequate to discharge through the electronic firing switch to a safe terminal voltage in a required time with no external terminal circuit, but whose value is otherwise not so low as to unnecessarily absorb a significant fraction of useful stored energy necessary to reliably initiate caps in the largest intended-external-cap circuit resistance. A step-up transformer and/or rectifier are connected to the main storage capacitor of the blasting machine and when supplied by alternating power will charge said main storage capacitor to a prescribed DC voltage, or a hand-cranked alternator and rectifier can be used to charge the storage capacitor. Generally, an internal main storage capacitor disarray resistor is connected either through a normally closed manual or electromagnetic relay contract across the main storage capacitor, in which case the disarray resistor value is selected to provide a discharge time constant of from one-half to 5 seconds, or it is connected directly across the main storage capacitor, in which case the disarray resistor value is selected and large enough to permit the charging the main storage capacitor through the step-up transformer and rectifier with the available alternating power source within a specified machine charging time requirement of from 5 to 30 seconds. A source of alternating power such as a standard commercial AC power line or a combination of DC battery and oscillator circuit, supplied the step-up transformer. The blasting machine also contains a normally open, and optionally remotely, operable power circuit closure means, insulated output terminal connectors for connecting the output terminals to an electric blasting cap-firing circuit and means for visually indicating either that the machine is charging and will fire at the prescribed minimum firing voltage in a determinable period of time if allowed to continue to charge, or that the machine is partially charged and will fire automatically at the prescribed minimum firing voltage in a determinable period of time if allowed to continue to charge, or that the machine is charged to the minimum prescribed voltage level and will fire if manually triggered.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the present invention are illustrated schematically in the attached FIGS. 1 to 3 wherein:

FIG. 1 represents a 25 joule capacitor blasting machine that incorporates a predetermined minimum voltage interlock discharge-control means;

FIG. 2 represents a remote controlled 400 joule capacitor blasting machine having an interlock that assures availability of the desired minimum voltage in the main firing capacitor before the electronic firing switch is triggered, and

FIG. 3 represents a blasting machine of FIG. 2 modified for manual control.

DESCRIPTION OF PREFERRED EMBODIMENTS

The improved blasting machines of the present invention are described in greater detail with reference to the accompany Figures. Like numbers are used to designate like parts and components of the blasting machines and blasting machine circuits that are illustrated schematically in the Figures.

Referring specifically to FIG. 1, a blasting machine rated at 25 joules of stored energy, 10 is the main storage capacitor, specifically having a capacitance of 12.5 μf farads, and capable of being charged to a potential in excess of 1,500 volts, more specifically to about 2,050 volts; 11 is a 5,000-ohm resistor which in series with normally closed contact of switch 24 shunts capacitor 10; 13 refers generally to the alternating current supply, that includes, for example, either 13-1 a 12-volt rechargeable battery or optionally 13-2, a 9-volt flashlight battery pack with battery connector terminals 13-3 to mate with the optional battery connector, a resistor 13-4 having a resistance of 3.9 ohms rated for 5 watts in series with the 12-volt battery connector, and polarized connector 13-5. For externally connecting a 12-volt battery charger, capacitor 13-6 has a capacitance of 160 μf farads, to filter the battery voltage so as to minimize peak battery currents, diode 13-7 to prohibit battery current flow if battery polarity is reversed, resistors 13-8, typically 2,200 ohms, 13-9, typically 1,000 ohms, and 13-10, typically 47 ohms, diodes 13-11 and 13-12, and transistor 13-13, all elements 13-1 through 13-13 taken together forming a battery-powered oscillator that is activated by closing power circuit-closing means, e.g., spring-loaded switch 14 that normally is in the open position and which may be located remotely with respect to case 20 or it may be included within the case 20 of the machine. The battery-powered oscillator supplies alternating current to the primary of transformer 21 wherein the voltage is stepped up and current is delivered from the secondary at a potential difference greater than, e.g., 2,000 volts, which alternating current is converted to pulsating direct current by rectifier 22, which may be connected through the parallel combination of neon indicator light 19, and resistor 23, and then is connected to the anode of two element arc gap firing switch 15. The cathode of arc gap firing switch 15 is connected to current output terminal 16. The other side of the step-up transformer is connected to terminal 12. The output
from rectifier 22 also is connected to main storage capacitor 10, the other side of which is connected to energy-output terminal 12, and capacitor shunt resistor 11 the other side of which is connected through normally closed contact of switch 24 to terminal 12. Output terminals 12 and 16 are connected to sockets 18 and 18-1, respectively, that are designed to receive jacks (not shown) which carry connecting cable that leads to the external electric cap firing circuit. Connected across output terminals 12 and 16 is internal shunt resistor 17.

In operation, spring-loaded switches 14 and 24 are depressed thereby opening the disarm circuit and connecting 12-volt battery 13-1, resistor 13-4, alternatively 9-volt battery 13-2 to the elements of the oscillation circuit that supplies alternating current to the primary of transformer 21. Transformer 21 steps up the voltage to a value greater than 2,000 volts, and the high voltage current is then changed to a pulsating direct current by rectifier 22 and thereby causes indicator 19 to glow while main firing capacitor 10 is being charged. Resistor 11 shunts capacitor 10 and automatically discharges capacitor 10 if spring loaded switch 24 is released before the charging cycle is completed. While spring-loaded switch 14 is closed, and spring-loaded switch 24 is open, the power supply charges capacitor 10 to, for example, 2,050 volts in about 10 to 12 seconds. When capacitor 10 reaches the desired voltage, commensurate with the design of firing switch 15, the gap is bridged by ionized gas and closes the circuit connecting capacitor 10 to energy-output terminals 12 and 16. The resistance of internal shunt resistor 17 is low enough to maintain switch 15 in the ionized conductive state until all the useful energy stored in capacitor 10 is dissipated in the external cap-firing circuit. Shunt resistor 17 is of high enough resistance (typically about 20 times that of the cap-firing circuit) not to compete significantly with the cap-firing circuit for the energy being discharged from capacitor 10. After the caps have been initiated and the blast has occurred, spring-loaded switches 14 and 24 are released by the blaster. The gas in switch 15 no longer is conductive, and any charge remaining on capacitor 10 is dissipated through shunt resistor 11, thereby disarming and rendering the unit completely safe against accidental high voltage discharges.

A blasting machine of this design generally is used for firing electrical blasting caps arranged in series, but can be adapted to firing multiple series of caps connected in parallel. For purposes of firing much longer rounds including circuits in which all caps are connected in parallel a modification of the electronic switch, as described hereinbelow, is employed if energies substantially greater than 25 joules are required for firing blasts.

It will be recognized that a commercial electric power source such as a lighting circuit can be used as the current source for the operation of transformer 21, but batteries are preferred as the source of power in order to attain the greatest degree of flexibility and portability in use of this particular embodiment of a blasting machine of this invention. A power supply circuit of the kind exemplified by FIG. 1, as described hereinbelow, provides a substantially constant power input to the capacitor and hence charges the capacitor repeatedly in an almost uniform time. The blaster soon recognizes that the cap-firing circuit will be energized after substantially the same elapsed time each time that the power supply circuit switch 14 is closed. The presence of electronic switch 15 in the circuit insures that the cap-firing output circuit will not be energized until sufficient energy is stored in main storage capacitor 10 to insure firing all caps, with a desired reserve for surety and safety.

Since two-element electronic firing switch 15 will not tolerate repeated discharges of large amounts of energy, a modification of the blasting machine of FIG. 1 is preferred for use in firing large numbers of caps that require very long lead lines and stored energy in excess of 25 joules.

With reference to FIG. 2, this diagram represents schematically a capacitor discharge blasting machine of the present invention that is designed especially for use in initiating large numbers, i.e. 200 or more, of electric blasting caps in a parallel hookup, and preferably caps arranged in a reverse parallel arrangement. Further, with reference to FIG. 2 the main firing capacitor 10 of this machine is of such capacitance that when charged to 2,000 volts, the stored energy is at least 400 joules. The main electronic firing switch 24 is a three-element triggered arc gap that is activated by a triggering circuit that includes a two-element arc gap 25 connected through the parallel combination of capacitor 26 and resistor 27 to the primary of trigger transformer 28, the secondary of which is connected to the anode of three-element arc gap switch 24 and through resistor 31, to the third, or triggering element of main arc gap switch 24. The cathode of arc gap switch 24 is connected to blasting machine energy-output terminal 16. Alternating current received at connecting cable terminals 34 and 35 is supplied to the primary of stepup transformer 21, the secondary of which is connected to a load impedance to full wave rectifier indicated generally by 22, the high voltage output terminals of which are 32 and 33. High voltage output terminal 33 is connected through resistor 30 to main storage capacitor 10 that is in parallel with resistor 11, and to the triggering circuit including elements 25, 26, 27, 28 and 31 identified hereinabove. The second high voltage (>2000 volts) output terminal 32 is connected to the other side of capacitor 10, resistor 11, the above-mentioned triggering circuit, and to the second blasting machine output terminal 12. Shunt resistor 17 is connected across blasting machine output terminals 12 and 16. Interconnected elements between connecting cable terminals 34 and 35 and blasting machine output terminals 12 and 16 taken together are referred to generally as the power module of this embodiment of the blasting machine of this invention.

Two-wire insulated copper connecting cable, that need be no heavier than No. 14 gage, is represented by 36 and 37. This cable can be up to 5,000 feet in length and connects the terminals 34 and 35 of the power module of FIG. 2 with a remote control module that can be positioned at a distance up to 5,000 feet from the blasting area, if such is desired for the safety of operating personnel.

The remainder of this especially preferred embodiment of the blasting machine shown schematically in FIG. 2 is designated as the remote control module. In it
a standard 110-115 volt AC power source is connected to the remote control unit at terminals 49 and 50. Terminal 49 is connected through switch 48 to fuse 47, resistor 46 and resistors 38 through 42 (to compensate for changes in resistance with changes of length of connecting cables 36 and 37), depending on the position of compensating switch 51, to connecting cable 36 and terminal 35 of the power module unit. The primary of transformer 44 is supplied by the input voltage dropped across resistor 46 which voltage drop is in phase with the sum of the voltages dropped across compensating resistors 38-42 depending upon the position of switch 51, the voltage dropped across connecting cables 36 and 37 and the voltage dropped across the primary of transformer 21 while the secondary of transformer 44 delivers an AC voltage that is 180° out of phase with the input voltages dropped across compensating resistors 38-42, depending upon the position of switch 51 connecting cables 36, 37 and the primary of transformer 21. As the main storage capacitor is charged, the main storage capacitor voltage is reflected to the primary of transformer 21 with a value equal to the capacitor voltage divided by the transformer turns ratio. Capacitor 45, rectifiers 52 and 54, capacitor 53 and variable resistor 55 with neon light 67 comprises a voltage detector circuit which can be adjusted to cause light 67 to illuminate at approximate 32 volts.

This detector circuit is supplied with AC voltages which include: (1) the input voltage drop across compensating resistors 42 through 38 (depending on the position of switch 51) plus the input voltage drop across the interconnecting cables plus the input voltage drop across the primary of transformers 21, which sum may be referred to as V1, (2) the reflected main storage capacitor voltage at the primary of transformer 21, and (3) the voltage across the secondary of transformer 44 which may be referred to as V2 and which is 180° out of phase with V1. By selecting a particular value of resistor 46, V2 can be made equal to V1 and since V1 and V2 are 180° out of phase they will effectively cancel each other at the input to the detector circuit, which detector circuit becomes sensitive only to the reflected capacitor voltage. Variable resistance 55 is adjusted to light neon bulb 67 at a prescribed voltage level corresponding to the voltage reached in about two-thirds of the total time required to attain the discharge voltage (2,050 volts) in the power module.

In operation of the blasting machine of FIG. 2, switch 51 is set on one of contacts 38' to 42' and 43 to compensate in 1,000-foot increments for changes in length of connecting cables 36 and 37, and the blasting caps hooked up in parallel and, preferably, in reverse parallel arrangement, are connected to energy-output terminals 12 and 16. On closure of switch 48 by the blaster, capacitor 10 starts charging. After about 8 seconds indicator 67 starts blinking as a signal to the blaster that main storage capacitor 10 will be fully charged (2,050 volts) at the end of another four seconds. At full charge of main capacitor 10 as determined when, and only when, arc gap 25 becomes conductive, and a small current pulse is sent through the primary of stepup transformer 28 thereby generating a voltage pulse which appears at the trigger element of main arc gap 24 through resistor 31 and which causes partial ionization of the gas in main arc gap firing switch 24, which gas then becomes fully conductive at the firing voltage (2,050 volts) which in itself would not cause the main gap in switch 24 to ionize and become conductive. Arc gap switch 24 continues to carry current discharging main storage capacitor 10 until all useful energy in said capacitor 10 is discharged from the blasting machine energy-output terminals 12 and 16 to the blasting caps. Thus switch 24 is not activated until the highly reliable capacitor reaches the minimum prescribed voltage to assure that the minimum prescribed energy is stored in main storage capacitor 10, to ensure delivery of more than the minimum firing energy through energy-output terminals 12 and 16, to external blasting circuits which are designed to be fired with this particular blasting machine. Switch 48 is released, i.e., opened, after firing the round, charging of main storage capacitor 10 ceases, and any residual charge on main storage capacitor 10 is dissipated in shunt resistor 11, thereby rendering the blasting machine safe from accidental high voltage discharges.

The triggered spark gap firing switch 24 is capable of withstanding repeated current discharges in excess of 1,000 amperes for firing the large number of parallel-connected electric blasting caps 66 in the external firing circuit. To achieve this degree of dependability in repeated service, a triggered arc gap switch 24 is used. Preferably, switch 24 is a sealed cylindrical glass envelope containing oppositely disposed barium aluminore electrodes and a mixture of hydrogen-argon-kyrpton gas that fills the glass envelope. The switch has the following specifications. The anode-to-cathode dielectric strength with trigger floating is greater than 3,000 volts, and with trigger shorted to anode it is greater than 2,950 volts. The maximum anode-to-cathode quench voltage from a 200 microfarad capacitor is 150 volts into a 2-ohm load, and the minimum anode-to-cathode voltage required to fully ionize the gas when triggered is 1,800 volts. The life expectancy of the switch is greater than 30,000 discharges from a 200 microfarad capacitor at 2,050 volts into a 2-ohm load.

The actual voltage at time of discharge is controlled by arc gap 25 which is precisely designed to become conductive at 2,000 (~0.6, +100) volts in the case of a 400 joule capacity blasting machine. The gap 25 is identified as Bendix Part No. 10–374121–14 by the Bendix Corporation, Electrical Components Division, of Sidney, N.Y. Such gaps are designed to operate dependably for at least 30,000 pulses at even higher voltages, if needed for greater cap-firing capability.

Capacitor 10, arc gap 25, and main discharge switch 24 are critical components of the blasting machines of the present invention. With these components included, all mechanical switches, relays, and the like are eliminated, and the components from current input terminals 34 and 35 to current output terminals 12 and 16 can be physically supported and completely protected from water, corrosive gases, and other deteriorating influences by immersing the components in a potting compound, e.g., a plastic material. Capacitor discharge blasting machines of this invention assembled with the specified critical components have a tested charge-discharge service life of more than 30,000 cycles. Hence, potting of components is practicable, and provision need not be made for opening
the modules for periodic replacement of short-life critical components.

Another desirable embodiment of the present invention is shown schematically in FIG. 3, the design and operation of which are described in the succeeding paragraphs.

This easily portable, high energy, capacitor discharge blasting machine is of general design, intended to handle from 50 to over 400 joules of cap-initiating energy. The machines of varying cap-initiating capabilities differ only in the size of the main capacitor 10, and in the selection of components 13, 21, and 22 in the power supply (oscillator) module, to provide from 10 to 30 seconds charging time. This design employs manual charge and fire switches 56 and 57 respectively, each having a normally closed contact in series with the disarm shunt resistor 11. Closure of the normally open contact of charge switch 56 completes the battery connection to the power oscillator and the normally open contact of the fire switch 57 provides a trigger pulse to the main three element arc discharge gap 24 through a minimum voltage interlock circuit involving two-element spark gap 25.

When the fire switch 57 is depressed, the disarm circuit is opened (removing shunt resistor 11 from the main capacitor 10), and the rechargeable battery 13-1 is connected to the main 20-watt oscillator to supply step-up transformer 21. The high voltage output of 21 is converted to DC by the half wave rectifier diode 22. The disarm shunt resistor 11 is disconnected from the main capacitor 10 and fire switches 56 and 57, respectively.

Main capacitor 10 is selected to store energy at high voltage with low capacitance to optimize the cap-initiating efficiency of the blasting machine. Accordingly, the minimum firing voltage is selected, in the order of 2,000 volts, and the capacitance of 10 is then determined by total firing energy requirement for the machine. Once the minimum firing voltage is selected, the design of the two-element arc discharge gaps 62 and 25, and the three-element arc gap 24 are determined according to the following plan.

The main capacitor discharge arc gap 24 which connects capacitor 10 to firing terminals 12 and 16 is set to ionize when triggered, at a capacitor voltage below the minimum prescribed firing voltage and must not ionize without a trigger pulse until the gap voltage is considerably higher than the maximum possible capacitor voltage. Hence, if the minimum firing voltage is 2,00, arc gap 24 must fire when triggered at, for example, 1,800 volts. Two-element arc gap 25 is designed to ionize at not lower than the minimum firing voltage and as close as possible to this voltage. Hence, when the voltage across capacitor 10 reaches the range of 2,000 to 2,050 volts, arc gap 25 discharges through resistance 58, capacitor 59, and resistances 60 and 61, and the neon indicator light 19 indicating that the machine has reached its firing voltage level. Only under this condition can a trigger pulse be connected to the trigger circuit by depressing firing switch 57. When firing switch 57 is depressed, a current pulse from arc gap 25 drops a voltage across resistance 58 and capacitor 59 which is connected through depressed firing switch 57, through resistance 27 and capacitor 36 to the primary of the trigger pulse transformer 28. This current pulse then generates a trigger pulse, in the secondary of transformer 28, that is used to trigger three-element arc gap 24 through resistance 31.

Another circuit-shunting main capacitor 65 includes two-element arc gap 62 in series with resistor 63 and the combination of resistance 64 and capacitance 65. Arc gap 62 is set to fire at some voltage above the minimum firing voltage of gap 25 and above the triggerable firing voltage of arc gap 24, but below the untriggered firing voltage of arc gap 24, and acts to limit the maximum voltage to which capacitor 10 can be charged, for protection against excessive voltage. The combination of arc 62 and resistor 63 and resistance 64 dissipates the power supply output when the voltage across capacitor 10 reaches the limiting value, typically 2,200 volts.

The resistance of the internal terminal shunt resistor 17 is small enough to ensure continuous ionization of the main three-element arc gap 24 until all useful energy stored in capacitor 10 has been delivered to the cap-firing circuit, but is large enough to avoid significant dissipation of useful energy in resistor 17 that typically has a resistance about 10,000 ohms.

The design of the main arc gap 24 which connects the main capacitor 10 to the firing terminals 12 and 16 is capable of repeatedly (30,000 or more cycles) discharging peak currents in excess of 2,000 amperes at voltages in the order of 2.0 to 2.5 kilovolts, with extremely low internal resistance, without arcing prematurely (before trigger pulse is applied), is physically small (compared to comparable mechanical or electromechanical switches with equivalent ratings), and is economical in cost and weight. Once deionized (upon reaching the quenching voltage), the arc gap 24 must be returned to the minimum firing voltage level and retriggered before it can be refrined. Thyatron and silicon controlled rectifiers may also be used in this application, but are unable to withstand such high peak currents and/or voltages, are considerably less reliable, and, in the case of parallel-connected or higher powered silicon controlled rectifiers, cost considerably more.

The blasting machine of FIG. 3 is not separable into control and power modules. Instead the whole machine is placed in a location remote from the blasting area and safe for the operator of the machine. Furthermore, the machine is so designed that, after being fired by depressing firing switch 57, both switches 56 and 57 are released, and residual energy in capacitors 10, 26, 59 and 65 is leaked off by the accompanying resistors so that the machine is inactivated and rendered safe against accidental discharges through terminal connecting means 18 and 18a or through connecting cables that are connected to machine energy-output terminals 12 and 16. The electrical elements of the current supply and discharge circuits can be potted in abuse- and corrosion-resistant high impact plastic cases, leaving easily accessible for replacement, if necessary, battery 13-1 and mechanically linked charge and fire switches 56 and 57, respectively. The use of the blasting machine of FIG. 3 to fire large rounds cannot result in missed holes if the blasting caps are properly connected to the bus wires since the machine will not discharge, even if fire switch 57 is prematurely depressed, because the electronic arc gap discharge
switch 24 is not activated unless main firing capacitor 10 is fully charged to the minimum firing voltage that is controlled by arc gap 25.

We claim:

1. A condenser-discharge blasting machine for initiating electro-explosive devices comprising, in combination,
   a. a nonelectrolytic main storage capacitor, including means for charging said capacitor to a potential in excess of 1,500 volts, said capacitor being capable of discharging currents in excess of 1,000 amperes, one side of said capacitor being connected directly to one of two energy-output terminals;
   b. an electronic firing switch as the sole means of circuit closure connecting the other side of said main storage capacitor to the second energy-output terminal;
   c. means for insuring that said electronic firing switch will discharge the main storage capacitor at a prescribed minimum voltage in excess of 1,500 volts;
   d. means for connecting said energy-output terminals to a circuit containing an electro-explosive device, and
   e. means for disarming the main storage capacitor.

2. An apparatus of claim 1 wherein means for charging said main storage capacitor is a hand-cranked alternator and a rectifier circuit.

3. The apparatus of claim 1 wherein the means for charging said main storage capacitor is a 110-440 volt AC power line connected through a normally open circuit closure control to the primary of a step-up transformer, the secondary of which is connected to the main storage capacitor through a rectifier circuit.

4. A blasting machine of claim 1 wherein the means for charging the main storage capacitor is a battery connected to an oscillator circuit through a normally open circuit closure control that supplies alternating current to the primary of a step-up transformer, the secondary of which is connected to the main storage capacitor through a rectifier circuit.

5. A blasting machine of claim 3 wherein the circuit closure controls are spaced at least 100 feet from the blasting machine energy-output terminals.

6. A blasting machine of claim 4 wherein the circuit closure controls are spaced at least 100 feet from the blasting machine energy-output terminals.

7. A blasting machine of claim 1 wherein the electronic firing switch comprises a two-element spaced arc gap enclosed within a casing containing an ionizable gas.

8. A blasting machine of claim 1 wherein said electronic firing switch is a triggerable three-element arc gap enclosed within a casing containing an ionizable gas.

9. A blasting machine of claim 8 in which the electronic firing switch has a main untriggered gap breakdown voltage which is substantially higher than the prescribed blasting machine firing voltage, and which can be triggered to fire with a main gap voltage substantially below the prescribed firing voltage, the input of said three-element arc gap being connected to one terminal of the main storage capacitor and the output of said three-element arc gap being connected to the first of two energy-output terminals and the other side of the main storage capacitor being connected directly to the second energy-output terminal, said electronic firing switch cooperating with (a) a pulse-triggering transformer the secondary of which is connected in series with a resistor between the output to the three-element arc gap and the triggering element of said three-element arc gap; (b) a pulse-shaping circuit comprising a resistor and capacitor in parallel, said pulse-shaping circuit connected in series with the primary of the pulse-triggering transformer and a two-element arc gap which series circuit is connected parallel to the main storage capacitor, said two-element arc gap having a gap spacing that insures conduction automatically when the main storage capacitor reaches the prescribed firing voltage thereby generating a trigger signal of suitable polarity and strength that renders the three-element arc gap conductive.

10. The blasting machine of claim 9 in which a normally open circuit closure device is connected in series with the pulse-triggering transformer.

11. The blasting machine of claim 10 in which a voltage limiting circuit is positioned across the main storage capacitor.