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3,075,125

EXPLODERS

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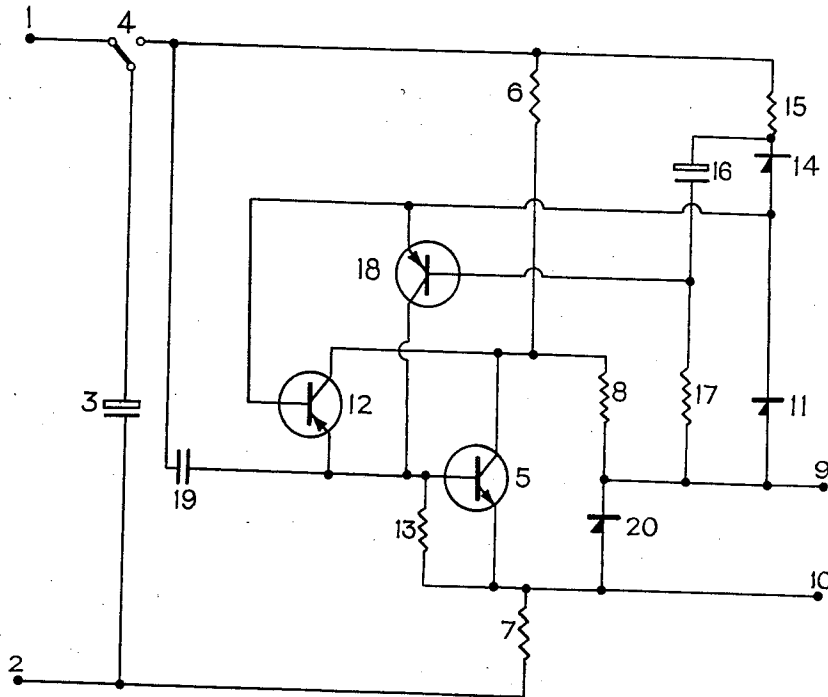


FIG. 1

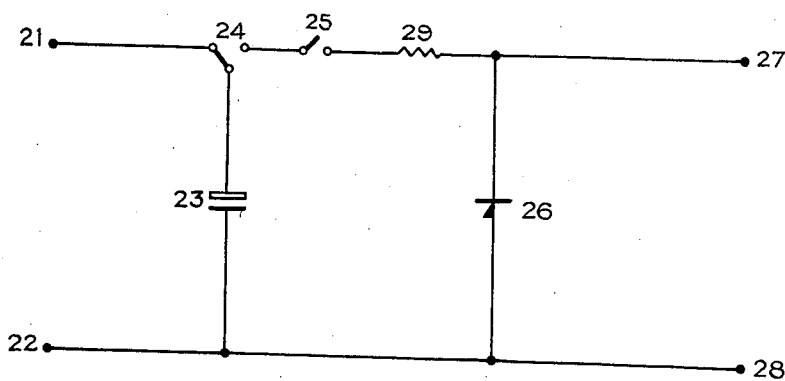


FIG. 2

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3,075,125 EXPLODERS

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This invention relates to improvements in exploders suitable for use in coal mines. The use of electric detonators in coal mines has become a generally accepted practice but the scope or their application is strictly controlled by regulations because of the danger of igniting methanes/air/coal dust in the atmosphere. At the present time the maximum number of shots that can be fired in coal, in one round, is limited to six. This limit, which is governed by safety considerations, is determined by the character of the exploder. Each detonator in a round requires at least 5 mj. (milli Joules) to ignite it whereas 1 mj. is sufficient to ignite a sensitive methane/air mixture. A suitable six shot exploder must therefore supply 30 mj. to the firing circuit without releasing 1 mj. into a circuit break or short circuit. In practice there is a time delay before short or open circuits may appear; this period is set by the delay which occurs after the firing of the detonator and before there is appreciable movement of the ground. With instantaneous detonators this delay has been found to be somewhat more than 4 milliseconds, but if there is a delay between the initial application of energy to the fusehead and the firing of the explosive the time at which the rock movement occurs is correspondingly delayed. An exploder that delivers its energy within 4 milliseconds is therefore safer than one which takes a longer period.

It is known that sparks caused by breaking inductive circuits are more dangerous than those from capacitive or resistive circuits. This is because the inductive energy stored in the magnetic field must be dissipated and gives rise to short period surges of high voltage and current when the resistance of the circuit is suddenly changed. The six shot exploder at present permitted in coal mines in Great Britain is therefore designed as a capacitive discharge limited in application time by mechanical means to 4 milliseconds. The energy supplied by an exploder of this type changes with time the amplitude falling off exponentially according to the relationship

$$E = E_0 e^{-\frac{2t}{CR}}$$

where E is the energy remaining in the capacitor at time t, E₀ is the initial energy, C is the capacitance of the exploder and R is the resistance of the firing circuit.

To deliver a given energy E the initial voltage across the circuit and current through the firing circuit must be much higher than the mean voltage and current values. The hazard during the early part of the delivery period is greater than it would be if the firing current and voltage were maintained at the mean values, since the energy dissipated into a fault, such as a break of circuit or a short circuit, increases with increase in the current and voltage prevailing at the time of fault. If the energy output could be maintained at the mean amplitude for the full application time, the total energy delivered would be the same but the hazard would be reduced for a given energy output. This may be achieved by employing an assembly that produces a square wave energy output i.e. one in which the voltage and current rise abruptly to constant amplitudes and fall abruptly again after a period of time. For maximum safety the values of voltage and current of the energy output should be controlled to the

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minimum values which will deliver the required energy within the time required for appreciable movement of the rock to take place after the firing of the detonators in a blast. Other types of exploder in which the electrical energy is supplied directly to the output circuit although not requiring excessive voltages and currents to fire electric detonators are also subject to the disadvantage that they may supply very high currents if the firing circuit is accidentally short circuited, and the use of some form of current control is desirable with these exploders also.

An exploder which provides a square wave output, and that is designed for firing twelve shots at the same time, has been described in Research Report No. 160 (March, 1959) of the Safety in Mines Research Establishment. This exploder employs a lumped parameter transmission line as the storage reservoir for energy, the line being permanently charged until switched to the firing circuit. This exploder has shown an improvement in safety in gas ignition tests over those currently used but it would be desirable to provide one which is less expensive to construct, and would have the additional advantages that in the event of accidental short circuit it would not pass a high current and an open circuit would not develop a high voltage.

The object of the present invention is to provide exploders which when used to fire electric detonators in coal mines will be inherently safer than exploders used hitherto, and which, at the same time, may be produced at a reasonable cost.

According to the present invention an exploder for firing electric detonators and the like includes in circuit with a source of electrical energy one or more solid semi-conductors arranged to control electrical characteristics of the output energy so that the values of these characteristics are maintained within predetermined limits such as to render the firing of electric detonators in firedamp atmospheres by the said exploder safer than it would be if the circuit of the exploder did not include the said solid semi-conductors.

The source of electrical energy is conveniently a dry battery and although the battery may be used to supply the output energy directly it is preferred that the energy to the output terminals should be provided by the discharge from a capacitor which has been previously charged from a dry battery or other convenient source of electricity.

In a preferred form of the invention the duration of the application of the output energy is controlled so that the required energy is passed through the detonator circuit before any appreciable movement of the rock burden can take place and consequently breaks in the circuit caused by rock movement are prevented from occurring while energy is passing through the circuit. Using the normal instantaneous detonators it is preferred to control the duration of the output energy to less than 4 milliseconds by including in the exploder a mechanical or electrical time switch. Thus the time of energy application may conveniently be controlled by arranging for the output energy to be by-passed after the desired time through a transistor which is connected to a capacitor and arranged to conduct when the capacitor becomes charged to a certain value through a resistance. The timing circuit is arranged so that the charging of the capacitor commences simultaneously with the initial application of the output energy and the time when the condenser will be charged to the extent required to allow the transistor to conduct can be pre-determined by adjustment of the resistance in circuit with the capacitor.

The electrical characteristics of the output energy which are controlled by the solid semi-conductors are voltage and current. If the resistance of the firing circuit remains constant the voltage is proportional to the current so that

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control of either current or voltage effects control of both.

In an exploder in which the current is controlled the solid semi-conductor in the form of a controlling transistor may be connected in series with the output terminals so that the output current passes through the transistor to output terminals or it may be connected in parallel across the output terminals so that all current in excess of that desired is bypassed therethrough. We prefer to have the controlling transistor connected in parallel, i.e. shunt connected with the output terminals, since in the event of failure of the said transistor, which usually results in a short circuit forming across it, all the energy will flow through the transistor circuit and no energy will flow through the output terminals. The detonators will in this case fail to fire whereas with a series connected transistor failure of the controlling transistor could result in an excessive current flow.

When the current across the output terminals is controlled in accordance with the invention the maximum energy of any spark resulting from any short circuit will be limited. The inclusion of a time switch to limit the time of application of the output energy to ensure that the energy flow is finished before breaks in the circuit due to rock movement can occur, is also desirable to enhance the safety of the current controlled exploder. Using the timing device and controlling the current to a substantially constant value the current and voltage of the output energy have desirable substantially square wave patterns. As a further safeguard against the hazards involved with broken circuits it is preferred to incorporate in the exploder based on current control a device to limit the voltage from rising above a predetermined value in the event of the circuit breaking from any cause with consequent cessation of current flow. This device is conveniently a voltage regulating diode, which may conveniently be a solid semi-conducting diode.

A form of exploder in accordance with the invention in which the voltage of the output energy is controlled includes a semi-conducting voltage regulating device shunt connected to the output terminals. This device is conveniently a silicon voltage regulating diode. In this exploder, as in the exploder in which the current is controlled, it is preferred to incorporate a timing circuit, and in order to safeguard against excessive current in the event of a fault or short circuit in the output circuit it is preferred to include a high resistance in series with the output terminals.

In order to more fully illustrate the invention some circuits suitable for use in exploders in accordance with the invention will now be described with reference to the accompanying drawings.

FIG. 1 shows the schematic diagram of a circuit making use of a shunt-type current regulator and incorporating an output voltage limiting device and an arrangement to cut off the output after a pre-determined time.

FIG. 2 schematically illustrates another embodiment of the invention.

A suitable source of electrical energy, which can be small batteries of the hearing-aid type, is connected between the terminals 1 and 2 with the terminal 1 positive. The storage capacitor 3 is then charged to the voltage of the source of electrical energy. When the storage capacitor 3 is fully charged, the switch 4 may be operated and the storage capacitor 3 discharged into the transistor controlling circuit and the output load. The control transistor 5, which is of the n-p-n junction type, is connected with its collector to a resistor 6 and its emitter to a resistor 7, the other ends of these resistors being connected to the storage capacitor 3 when it is being discharged. An output is taken between the emitter and collector of the control transistor 5 through the reference resistor 8 to the output terminals 9 and 10. Any current which flows in a circuit external to the terminals 9 and 10, i.e. through the detonators, therefore passes through the reference resistor 8 causing a voltage drop across it in such a direc-

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tion that the end connected to the collector of the control transistor 5 is positive with respect to the end connected to the output terminal 9. A voltage regulating semi-conductor diode 11, which maintains a constant voltage drop across itself over a wide range of currents is arranged with its negative terminal connected to the negative end of the reference resistor 8. An amplifying transistor 12, which is of the p-n-p type, is arranged with its emitter connected to the positive end of the reference resistor 8, its base to the positive end of the voltage regulating semi-conductor diode 11 and its collector to the base of the control transistor 5. If the voltage drop across the reference resistor 8 is greater than the voltage of the voltage regulating semi-conductor diode 11, then base current will flow in the amplifying transistor 12 causing an amplified current to flow in its collector and in the base of the control transistor 5. This, in turn, results in an amplified collector current in the control transistor which flows through the resistors 6 and 7 and leads to a reduction in the voltage between the emitter and collector of the control transistor 5 which is applied to the output. Thus the collector current through the control transistor 5 is continuously adjusted in such a way that the voltage drop across the reference resistor 8, and hence the output circuit current, is maintained constant and approximately equal to the voltage of the voltage regulating semi-conductor diode 11. The resistor 13 is included to provide a fixed resistive path for part of the collector current of the amplifying transistor 12 and a low impedance for the base of the control transistor 5.

The timing circuit comprises the voltage regulating semi-conductor diodes 11 and 14, together with their feed resistor 15, a resistance-capacitance timing circuit comprising the timing resistor 17 and the timing capacitor 16, and the switching transistor 18. When the storage capacitor 3 is switched into the transistor controlling circuit by the switch 4, the current regulating action quickly adjusts circuit conditions and a certain voltage is developed across the series combination comprising the resistor 15 and the voltage regulating semi-conductor diodes 14 and 11. The action of the voltage regulating semi-conductor diodes is to produce across each of them a fixed voltage drop which is maintained substantially constant while the storage capacitor 3 discharges. The switching transistor 18 is connected with its emitter to the junction of the voltage regulating semi-conductor diodes 11 and 14, its base to the junction between the timing resistor 17 and the timing capacitor 16, and its collector to the base of the control transistor 5. Initially, the timing capacitor 16 is discharged, so that the base of the switching transistor 18 is positive with respect to its emitter. Under these conditions, the switching transistor 18 is maintained in the cut-off condition and no collector current flows. However, the timing capacitor 16 will immediately commence to charge through the timing resistor 17 and when the potential across the timing capacitor 16 is such that the base of the switching transistor 18 becomes negative with respect to its emitter, then the switching transistor 18 will pass collector current which will increase the base current of the control transistor 5 and cause this transistor to become fully conducting, thus reducing the output to zero.

The capacitor 19 is included so that the control transistor 5 is supplied with a very heavy base current during the time immediately following the switching action of switch 4 in order to make the control transistor 5 conduct very quickly and prevent the initial output current exceeding the desired value.

In order to prevent the voltage developed between the output terminals 9 and 10 rising to too high a value in the event of a break occurring in the output circuit a voltage regulating semi-conductor diode 20 is fitted to limit the maximum voltage. So long as the voltage appearing between terminals 9 and 10 under normal operation is less than the operating voltage of the voltage regulating semi-conductor diode 20, the said diode will not

by-pass any of the output current. If this voltage is exceeded, however, the voltage regulating semi-conductor diode 20 will by-pass current and prevent the voltage rising above the pre-determined value.

Since the base to emitter voltage of the control transistor 5 is small and the voltage across the reference resistor 8 is maintained constant, the voltage between the collector and base of the control transistor 5 is related to the output voltage. Alternatively, therefore, the voltage regulating semi-conducting diode 20 may be interposed in this position. In this case, however, it must have an operating voltage which exceeds the prescribed maximum output voltage by the magnitude of the voltage drop across the reference resistor 8. When the voltage between the collector and base of the control transistor 5 exceeds this value then a voltage regulating semi-conductor diode in this position will pass current to the base of the control transistor 5 and result in an amplified collector current in this transistor which will prevent any further rise in the output voltage.

An alternative form of voltage limiting device which can be used in either of the positions described is a p-n-p-n semi-conductor switching diode. This device has the property that provided the voltage across it does not reach a critical level, the diode does not conduct, but when this level is exceeded a rapid switching action takes place and the voltage across the device drops to a fraction of a volt. Thus if such a device is used in place of the voltage regulating semi-conductor diode 20, then if the output voltage developed between the output terminals 9 and 10 rises above the pre-determined value the device becomes conducting and reduces the output voltage substantially to zero.

The magnitudes of the voltage of the electrical energy source and the capacitance of the storage capacitor 3 are a compromise between the requirements that the voltage v of the electrical energy source should be fairly high, since the energy stored by the storage capacitor 3 will be in proportion to v^2 and that the change in voltage as the capacitor discharges during the time that the exploder is delivering current should be small in order to reduce the regulating action required of the system. In a particular exploder required to deliver a current of 1.35 amps. into output circuit resistances up to 33 ohms for a period of 4 milliseconds, it was found that a 100 volt battery was a suitable energy source when the storage capacitor 3 had a value of 500 microfarads. The value of the reference resistor 8 can be calculated from the operating voltage of the voltage regulating semi-conductor diode 11 and the value of current required. Thus in the example quoted above, the voltage regulating semi-conductor diode 11 has a nominal operating voltage of 6.2 volts and the reference resistor 8 is adjusted to a value a little below 5 ohms. The values of the timing capacitor 16 and the timing resistor 17 may be calculated approximately from the formula $T = C.R$ where T is the value of the time required in milliseconds, C the value of the timing capacitor 16 in microfarads and R the value of the timing resistor 17 in kilohms. The maximum value of the timing resistor 17 is, however, limited by the necessity of passing sufficient current to the base of switching transistor 18 in order to make transistor 5 fully conducting. In the example quoted above the value of the timing capacitor 16 is 5 microfarads and the timing resistor 17 is adjusted to a value a little below 1 kilohm.

FIGURE 2 shows the schematic diagram of a circuit incorporating a shunt voltage regulator and a mechanical time switch. The source of electrical energy, which may be in the form of a battery of the hearing-aid type, is applied to the input terminals 21 and 22. With the switch 24 in the position shown the storage capacitor 23 will be charged to the voltage of the electrical energy source. When the switch 24 is operated the said capacitor will be discharged into the output circuit. A mechanical timing switch 25 is incorporated in the output circuit and is usually operated simultaneously with the switch 24. The

voltage regulating semi-conductor diode 26 is connected directly across the output terminals 27 and 28 and to the storage capacitor 23, during its discharge, by the load resistor 29. If the output circuit resistance between the output terminals 27 and 28 is sufficiently large the voltage across the output will rise as soon as the capacitor 23 is connected to the regulating circuit until the voltage regulating diode 26 commences to conduct. Sufficient current will then be diverted through the voltage regulating semi-conductor diode 26 to produce a voltage drop across resistor 29 such as to maintain the voltage between the output terminals 27 and 28 at the pre-determined maximum value. If the resistance between the output terminals 27 and 28 is low then the voltage between these terminals will not rise to the operating voltage of the voltage regulating semi-conductor diode 26 and no current will be by-passed through this device. The output voltage will then depend on the charge in the storage capacitor 23, the relative magnitudes of the load resistor 29 and the resistance between the output terminals 27 and 28. At the completion of the desired period of time, the time switch 25 will open disconnecting the storage capacitor 23 from the output circuit.

In circuits which are required to dissipate considerable power it may be desirable to incorporate with the simple voltage regulating semiconductor diode 26 one or more transistors. The magnitude of the storage capacitor 23, the voltage of the energy source and the value of load resistor 29 should be chosen such that for the particular resistance used in the external circuit the voltage across the output terminals 27 and 28 should not be less than the limiting voltage of the regulating semi-conductor diode 26, at the end of the pre-determined energy application time. The value of the load resistor 29 must also be chosen so as to limit the peak current to a safe magnitude when the capacitor 23 is first switched to the discharge position.

Circuits incorporating solid semi-conductor devices to limit the current and voltage in the manner described and illustrated may be assembled in a compact form in the normal type of casing used for exploders and the exploders incorporating such circuits may optionally also include testing devices, safety switches and the like.

What we claim is:

1. An exploder for firing electric detonators and the like, which comprises in combination, a pair of output terminals, a source of electrical energy having two pole pieces at different electrical potential, one of the said pole pieces being coupled to one of the said output terminals, two resistors, one of which is a ballast resistor and the other a reference resistor, electrically connected at a junction, the other end of the ballast resistor being connected to the other pole piece and the other end of the reference resistor being also connected to the said other output terminal, at least one control transistor having a base electrode and two other electrodes, and a constant voltage device having two electrical leads, one of the said leads being coupled to the base electrode of the said transistor and the other being coupled to the said other output terminal, one of the two other electrodes of the transistor being coupled to the said junction between the said two resistors and the other being coupled to the said one output terminal, the resistance of said ballast resistor being chosen in accordance with the characteristics of the said control transistor, the potential difference between the said pole pieces, the resistance of the external detonator circuit, and the desired output current, the resistance of the said reference resistor and the characteristic voltage of the said constant voltage device being chosen in accordance with the desired output current.

2. An exploder as in claim 1 wherein the source of energy is a charged capacitor.

3. An exploder as in claim 1 and further including an amplifying transistor having a base electrode and two other electrodes, the base of the said amplifying transistor being connected to the lead of the said constant volt-

age device remote from said other output terminal, one of the other electrodes of the said amplifying transistor being connected to the base electrode of the said control transistor, and the remaining electrode being connected to the said junction of the said two resistors.

4. An exploder as in claim 1 and further including means for limiting the output voltage appearing across said output terminals.

5. An exploder as in claim 4 wherein said voltage limiting means includes a voltage regulating semi-conductor diode.

6. An exploder as in claim 4 wherein said voltage limiting means includes a p-n-p-n semi-conductor switching diode.

7. An exploder as in claim 4 wherein said voltage limiting means is connected to the said one output terminal and to the junction between said reference resistor and the said other output terminal.

8. An exploder as in claim 1 and further including a timing switch to control the duration of the output energy.

9. An exploder as in claim 8 wherein said timing switch includes a capacitor-resistor timing circuit and a switching transistor controlled by the timing circuit to bypass said output energy after a desired time interval.

10. An exploder as in claim 8 wherein said source of energy is a charged capacitor.

11. An exploder as in claim 10 and further including

means for limiting the output voltage appearing across said output terminals.

12. An exploder as in claim 10 and further including an amplifying transistor having a base electrode and two other electrodes, the base of said amplifying transistor being connected to the lead of the said constant voltage device remote from said other output terminal, one of the other electrodes of said amplifying transistor being connected to the base electrode of the said control transistor, and the remaining electrode being connected to the said junction of said two resistors.

13. An exploder as in claim 12 and further including a semi-conductor device connected to limit the output voltage appearing across said output terminals.

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