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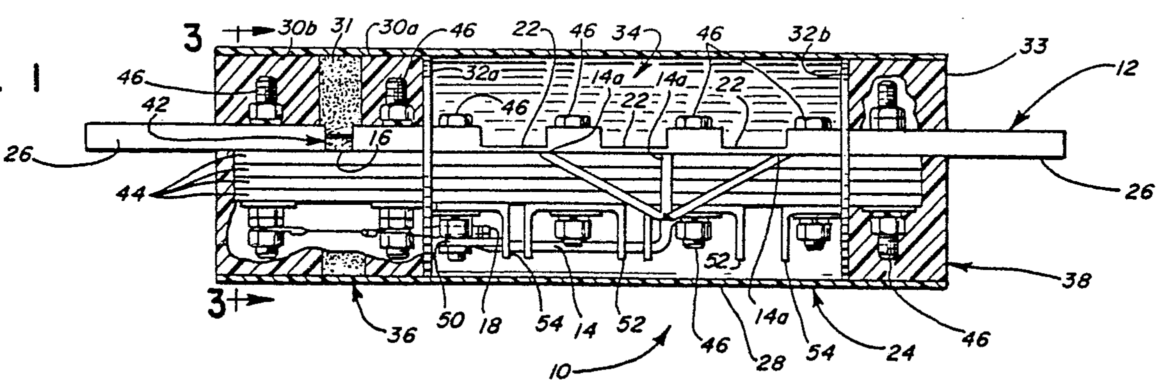
(54) **Current interrupter.**

(57) A current interrupter (10) wherein current is normally carried by a bus bar (12), and a portion of the bus bar (12) is segmented by a pyrotechnic charge (14) under excess current conditions. The charge (14) is detonated by a detonator (18) which is triggered by voltage across a resistive element (16) having a predetermined melting point connected in series with the bus bar (12). At the time the detonator (18) is triggered, the resistive element (16) provides sufficient resistance to trigger the detonator (18) while operating at a temperature below its melting point. A control device (20) may be employed to control current flow through the detonator (18).

FIG. 1



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CURRENT INTERRUPTER

This invention relates to apparatus for automatically interrupting current in an electric circuit under overload conditions, and more particularly to such apparatus for use in relatively high current applications.

The current in electric circuits must be interrupted automatically under overload or fault conditions, especially those caused by short circuits and the like, to prevent possible damage to the circuit components. In relatively high power equipment, such as power distribution and transmission apparatus used by utilities, the current must be limited in magnitude and interrupted very rapidly when an overload condition occurs, preferably within one quarter of a cycle, before the current reaches even one amplitude peak.

Current limiting devices have been developed which are capable of limiting the current in about 200 microseconds, and interrupting it in less than one quarter of a cycle. Such devices generally include a fusible element which is placed in sand or the like. The fusible element includes one or more portions of reduced cross-section. An overload current melts the element at the portions of reduced cross-section, creating arcs. The sand abosrbs enough energy from the arcs to extinguish them, and the current is interrupted. Such high voltage fuses have a relatively low continuous current carrying capability of about 200 amperes.

In one known type of current limiting interrupter with higher continuous current carrying capability, a large cross-section conductor or bus bar carries the current under normal operating conditions. When a fault such as a short circuit occurs, a linear pyrotechnic charge breaks the conductor into segments. In relatively low voltage applications, the sum of the arc voltage drops across the gaps thus created is sufficient to interrupt the current. In high voltage applications, the sum of these arc voltages would be too small to effect current limited interruption. Therefore, the curent is commutated to a parallel current limiting fuse and the element of the current limiting fuse melts and causes current limited interruption in a conventional manner.

While current interrupters of the type described above have proven effective, they have been relatively expensive. A substantial portion of the cost of commercially available current interrupters of the above-described type is attributable to electronic equipment which is used to sense excessive current and ignite the explosive charge. This equipment may include isolation transformers, a current sensing transformer, and solid-state triggering logic. An external line voltage power source is generally needed for this equipment which further adds to the cost of the system and its installation. There is a need for a less expensive triggering system for sensing excessive current and detonating the pyrotechnic charge in pyrotechnic current interrupters. There is also a need for a triggering system which does not require external power sources or external connections. Past attempts to address these needs are disclosed in US-A-4538133 and US-A-4479105.

According to the invention there is provided apparatus for automatically interrupting current in an electric circuit, characterised by elongate bus means; explosive means for segmenting said bus means; resistive means having a predetermined melting point connected in series with said bus means; and detonator means connected in parallel with said resistive means to detonate said explosive means, said detonator means having a predetermined trigger level, and said resistive means having a resistance such that in response to a fault current through said bus means the trigger level of said detonator means is exceeded while the temperature of said resistive means is below said predetermined melting point.

The invention provides a current interrupter in which explosive means such as a pyrotechnic charge segments a bus means such as a bus bar. The resistive means constitutes an overload detection device which provides a voltage drop that increases with increased current flow therethrough and the explosive means is detonated by the detonator means. During normal current conditions the voltage across the resistive means and detonator means is insufficient to trigger the detonator means, but when excessively high current flows through the apparatus, the voltage increases sufficiently to trigger the detonator means.

The resistive means may comprise a strip of metal having a resistivity which increases with increased temperature.

Control means may be provided to control current flow through the detonator means and enable various trigger levels to be available for an apparatus having a particular resistive means and detonator means.

The invention will now be described by way of example with reference to the drawings, in which:-

Figure 1 is a side elevational view, taken partially in section with portions broken away, of apparatus in accordance with the invention;

Figure 2 is a bottom view, taken partially in section with portions broken away, of the apparatus of Figure 1;

Figure 3 is a sectional view taken along line 3-3 in Figure 1, shown with portions broken away;

Figure 4 is a schematic diagram illustrating the apparatus of Figure 1 in combination with control means and a parallel current limiting fuse; and

Figures 5-10 are schematic diagrams illustrating six different control circuits for use in apparatus in accordance with the invention.

The apparatus to be described is a pyrotechnic current interrupter 10 which employs a bus means in the form of a bar 12 to conduct current under normal conditions, and employs explosive means in the form of a linear pyrotechnic cutting charge 14 to sever the bus bar 12 at spaced locations when excessively high current flows through the bus bar. To sense excessively high current and detonate the charge in response thereto, overload detection means in the form of resistive means 16 are connected in series with the bus bar 12, and a detonator means 18 is connected in parallel with the resistive means 16. During normal current conditions the voltage drop across the resistive means 16 and detonator means 18 is insufficient to trigger the detonator means 18, but when excessively high current flows through the interrupter 10 the voltage drop increases sufficiently to trigger the detonator means 18.

The detonator means 18 has a predetermined trigger level which may be expressed as the quantity of energy input required to effect detonation. For purposes of the present analysis, this energy input is dependent upon the integral of the square of the current over time. Similarly, the interrupter 10 has a trigger level which is determined by the trigger level of the detonator means 18 and the relationship between current flow through the detonator means 18 and current flow through the bus bar 12.

The electrical resistance of the detonator means 18 is related to that of the resistive means 16 such that when fault current begins to flow through the interrupter 10, the current level through the detonator means 18 reaches a sufficient level for a sufficient time to trigger the detonator means 18 while the temperature of the resistive means 16 is below its melting point. Control means 20 (Figures 4-10) may be provided to vary the trigger level of the interrupter 10.

The bus bar 12 has a series of portions 22 of reduced cross-section formed therein to facilitate formation of gaps by the pyrotechnic charge 14. The pyrotechnic charge 14 illustrated is a cord such as Primacord, and is arranged so as to have respective portions 14a extending transversely across the bus bar 12 beneath each of the portions 22 of reduced cross-section in the bus bar 12. Upon detonation, the portions 22 of reduced cross-section are cut and folded upward.

The bus bar 12 is partially enclosed by a generally cylindrical housing 24. The ends 26 of the bus bar 12 protrude from the housing 24. The housing 24 includes a generally cylindrical side wall 28 and a pair of divider walls 32a and 32b which separate the interior of the housing into a central compartment 34 which contains the pyrotechnic charge 14 and detonator means 18, a first end compartment 36 which contains the resistive means 16, and a second end compartment 38. The central compartment 34 may be filled with air or with a dielectric gas.

The first end compartment 36 is filled by two plugs 30a and 30b, and a layer of sand 31 which is disposed therebetween. The plugs 30a, 30b are preferably made of a resin reinforced by glass fibers, and are preferably formed in the compartment 36 so as to conform to the shapes of the bolts, bus bar, etc.

To fill the compartment 36, the interrupter is placed on end so that the compartment 36 is uppermost, and a sealant is applied to the periphery of the transverse wall 32a. Glass fibers and resin are poured into the compartment 36 up to a level just beneath the resistive means 16 to form the first plug 30a, then the layer of sand 31 is added, followed by a second layer of glass fibers and resin to form the second plug 30b. The compartment 38 at the opposite end is similarly filled, but with a single plug 33.

The bus bar 12 has a transverse gap 42 formed therein and the resistive means 16 preferably comprises one or more thin strips of silver which extend longitudinally of the bus bar across the gap 42. The number of silver strips employed is determined by the current rating of the interrupter. To enable the interrupter to carry a continuous 200 ampere A.C. current, one silver strip is used. To enable the interrupter to carry higher continuous current, one additional silver strip is employed for each additional 200 amperes.

The resistance of the resistive means 16 is a function of (1) the total cross-sectional area of the strip or strips, (2) the width of the gap 42 --i.e., the effective length of the strip or strips --and (3) the resistivity of the strip or strips, which is a function of temperature. In the embodiment of Figures 1-3, each of the silver strips has a width of about 70mm (0.275 in.) and a thickness of about 1mm (0.004 in.) which provides a cross-sectional area of about .007 cm^2 (0011 in^2.). The width of the gap 42 in the bus bar is 1.27 cm (0.5 in.). When the interrupter operates at its rated amperage, the strips operate at or near 50° to 100° C. Each silver strip is soldered at both ends to the bus bar 12 and is immersed in the sand 31.

The preferred detonator means 18 is a low-energy, fast-acting device comprising an electrically conductive bridgewire which contacts a primary explosive. Detonation is effected by transfer of heat produced by the current through the bridgewire to the primary explosive. The preferred detonator has a resistance of about 2-5 ohms, several orders of magnitude above that of the resistive means 16.

The bus bar 12 is fastened to a stack of generally rectangular insulating plates 44 by a plurality of vertically extending bolts 46. The detonator means 18 is connected in parallel with the resistive means 16 by fastening its leads 48 to a pair of the bolts which contact the bus bar 12 on opposite sides of the gap 42 in end compartment 36.

The detonator means 18 is supported on a bracket 50 which is mounted on one of the bolts 46. The leads 48 extend through the divider wall 32a to the adjacent compartment 36. To prevent flow of current between the portions of the bolts 46 which extend beneath the plates 44 after detonation of the charge 14, transversely oriented channel members 52 and angle members 54 are bolted to the bottom of the stack of plates 44 so as to provide transversely-extending vertical walls between the bolts 46 that will be on opposite sides of a gap after segmenting of the bus bar 12 occurs.

Although the low energy detonator means 18 is of known construction, both the response time and the trigger level of the preferred detonator are significantly lower than those of more commonly used commercially available high energy detonators. The preferred detonator means has an "all fire" response time of 10 microseconds when subjected to current produced by discharge of a 0.4 microfarad capacitor charged to 50 volts. The energy input required to ensure detonation under standard conditions is about 0.0005 Joules. For purposes of comparison, more commonly used high energy detonators may require about .003 Joules for detonation.

The above-described interrupter provides reliable current-limited interruption of high voltage alternating current in the 200A-1000A range when connected in parallel with a current limiting fuse, and has a relatively low let-through current. For example, the let-through current for a 600 ampere interrupter as described above should be about 14,000 amperes for a prospective fault current of 25,000 amperes (rms, sym.).

To enable more precise control of the trigger level of the interrupter 10, the interrupter may include control means 20 as illustrated in Figure 4. The control means 20 preferably includes a device which provides a voltage drop or voltage threshold in series with the detonator means 18.

Referring particularly to Figure 5, the control means 20 shown therein comprises two series of diodes connected in series with the detonator means 18, in parallel with one another and in opposite directions. The diodes as shown provide a voltage drop or threshold in series with the detonator means to raise the trigger level of the interrupter. Two parallel series of opposite polarity are provided so that the trigger level of the interrupter will not vary according to the instantaneous direction of hte A.C. current. Switches are provided to enable current to bypass one or more of the diodes in each series so as to provide stepwise variability of the sensitivity of the interrupter. Because the switches enable external adjustment of the control means identical control means can be used for interrupters having various trigger levels, the selection of the trigger level of a particular interrupter can be made in the factory simply by setting of the switches to appropriate positions.

To enable continuous rather than stepwise adjustment of the trigger level of the interrupter, variable resistors are provided in the embodiments of Figures 7 and 10 in series with the detonator means 18. The variable resistors provide a continuously variable voltage drop in series with the detonator means. To prevent unintended triggering of the detonator due to power surges of very short duration, a capacitor may be connected in parallel with the detonator as shown in Figure 10.

Figures 6, 8 and 9 illustrate control means 20 which are not externally adjustable. In these embodiments the trigger level of the interrupter is selected simply by selection of appropriate components for the control means 20 rather than by manipulation of a control. Figure 6 illustrates a control means 20 wherein a pair of zener diodes are arranged in parallel with one another and in series with the detonator means, and oriented in opposite directions. As in the control means of Figure 5, the orientation of the diodes in parallel and in opposite directions enables the control means to provide a threshold-type trigger level for the interrupter which is not dependent on the instantaneous direction of the AC current. The control means of Figure 9 employs a metal oxide varistor (MOV) which has relatively high resistance when subjected to relatively low voltage in either direction, and has significantly lower resistance when subjected to higher voltage in either direction. As in the previously described control means of Figures 5-7 and 10, the control means of Figure 9 is independent of the instantaneous AC current direction.

It may be desirable in some applications to provide an interrupter having a trigger level which differs depending upon the instantaneous current flow. For such an application, the device of Figure 8 employing a single zener diode in series with the detonator means may be suitable.

Claims

1. Apparatus for automatically interrupting current in an electric curcuit, characterised by elongate bus means (12); explosive means (14) for segmenting said bus means (12); resistive means (16) having a predetermined melting point connected in series with said bus means (12); and detonator means (18) connected in parallel with said resistive means (16) to detonate said explosive means (14), said detonator means (18) having a predetermined trigger level, and said resistive means (16) having a resistance such that in response to a fault current through said bus means (12) the trigger level of said detonator mens (18) is exceeded while the temperature of said resistive means (16) is below said predetermined melting point.

2. Apparatus in accordance with Claim 1, characterised in that said resistive means (16) comprises a strip of metal having a resistivity which increases with increased temperature.

3. Apparatus in accordance with Claim 1 or Claim 2, characterised in that said detonator means (18) comprises a detonator having a high current response time of about 10 microseconds.

4. Apparatus in accordance with any preceding claim, characterised by control means (20) cooperating with said resistive means (16) to control current flow through said detonator means (18).

5. Apparatus in accordance with Claim 4, characterised in that said control means (20) is connected in series with said detonator means (18), and said resistive means (16) is connected in parallel with the series connection of said control means (20) and said detonator means (18).

6. Apparatus in accordance with Claim 4 or Claim 5, characterised in that said control means (20) has variable resistance.

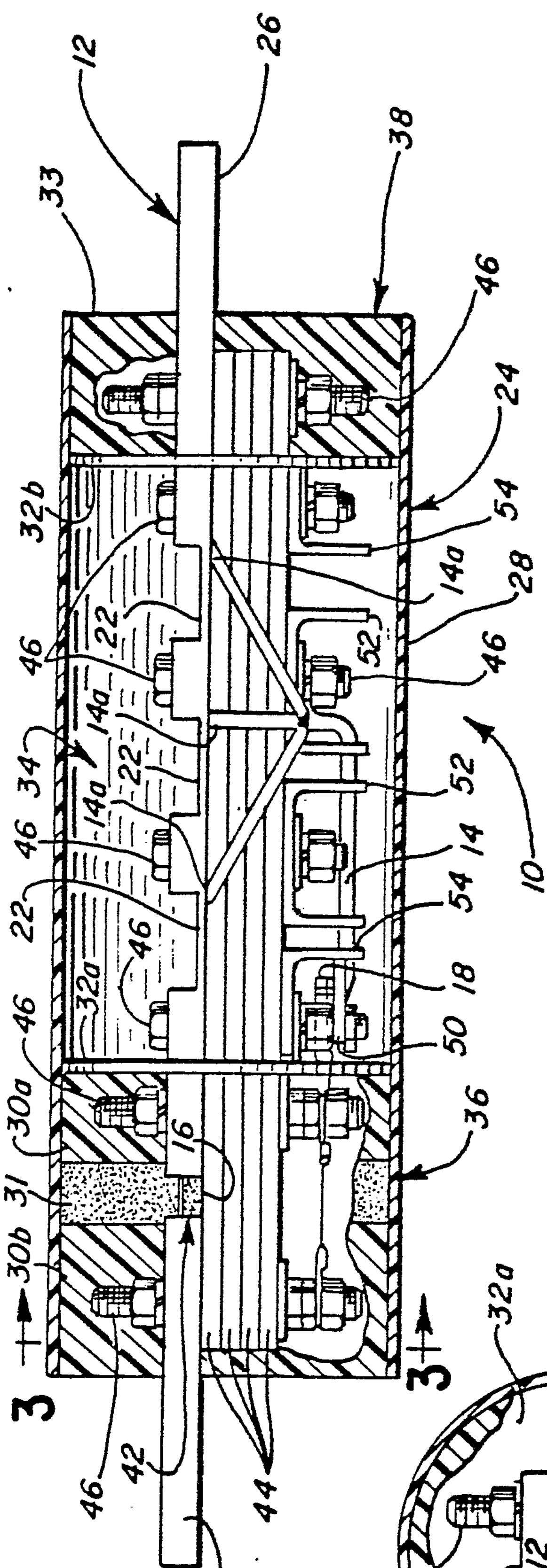


FIG. 1

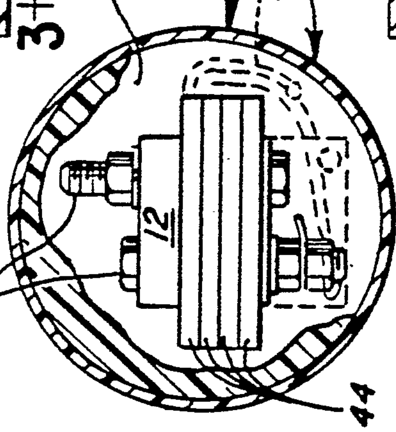


FIG. 3

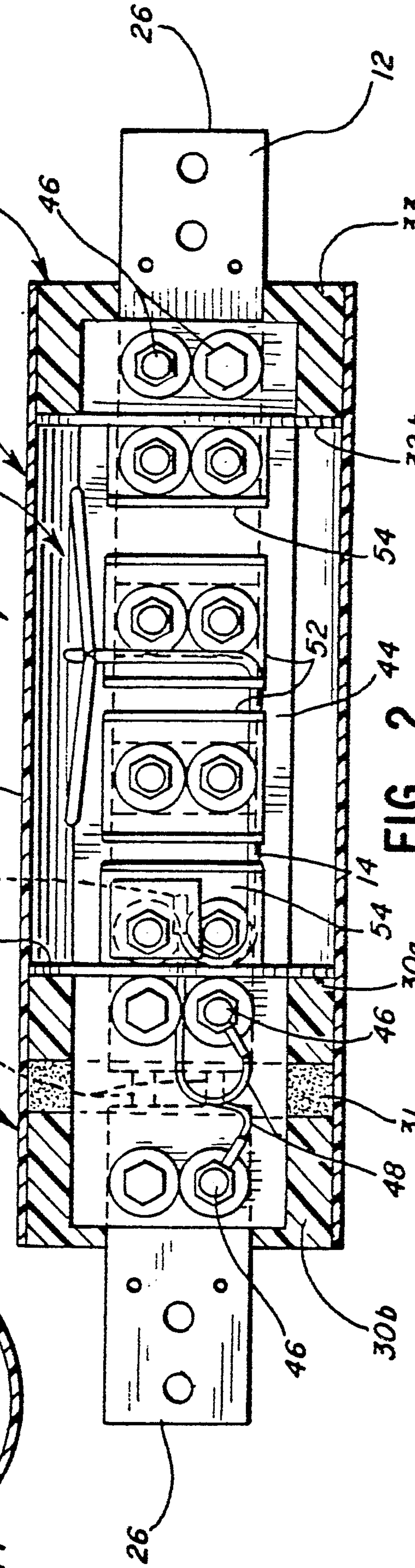


FIG. 2

FIG.4

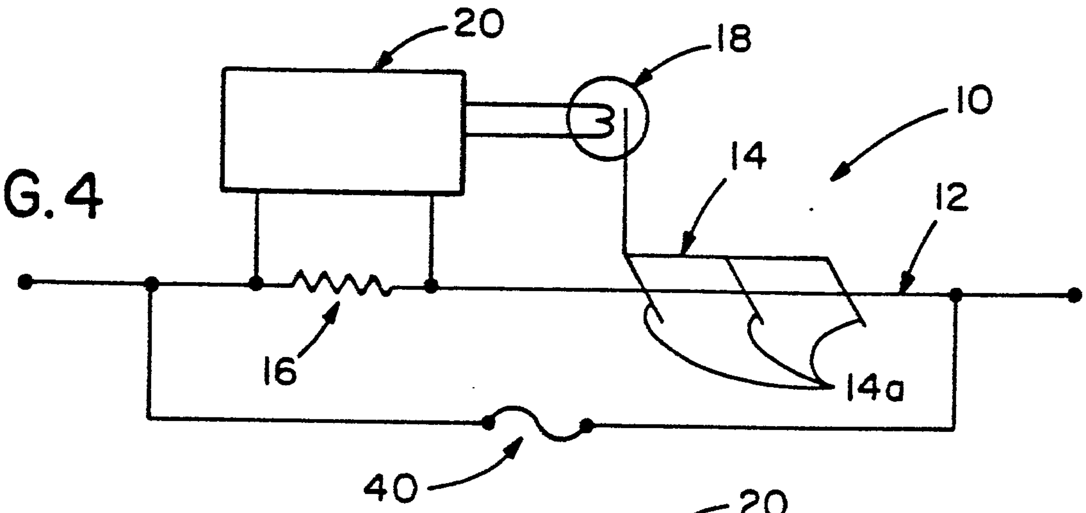


FIG.5

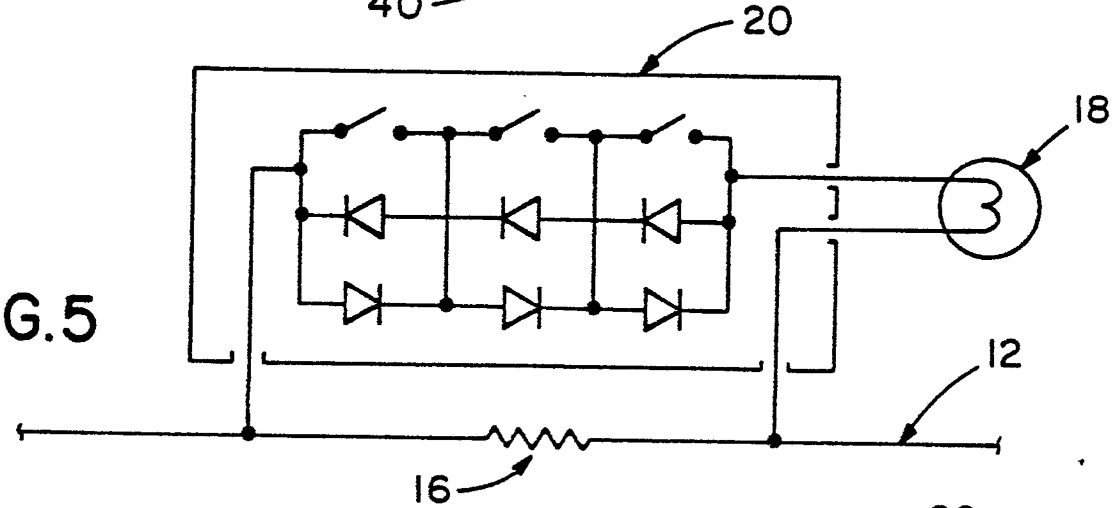


FIG.6

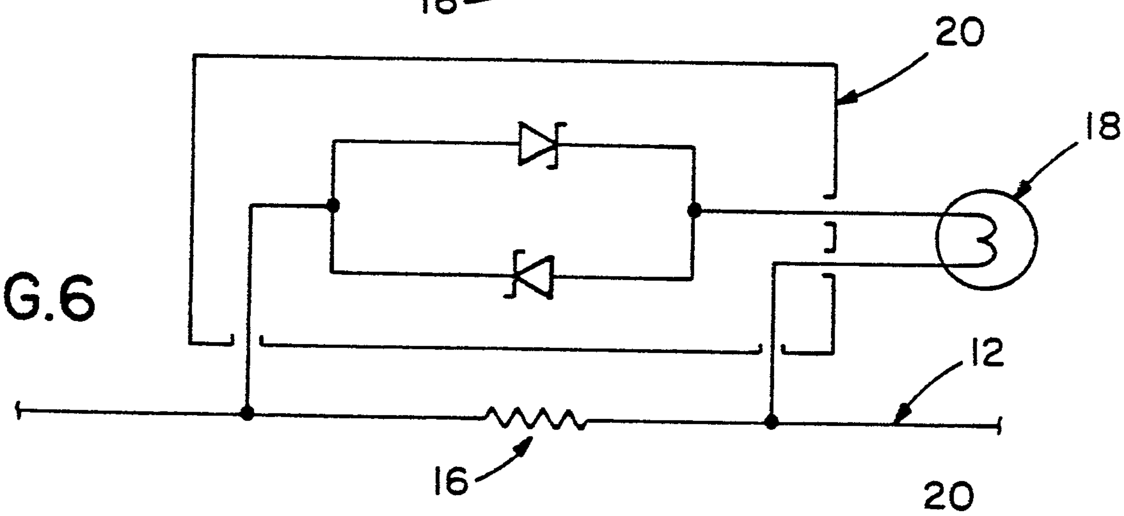
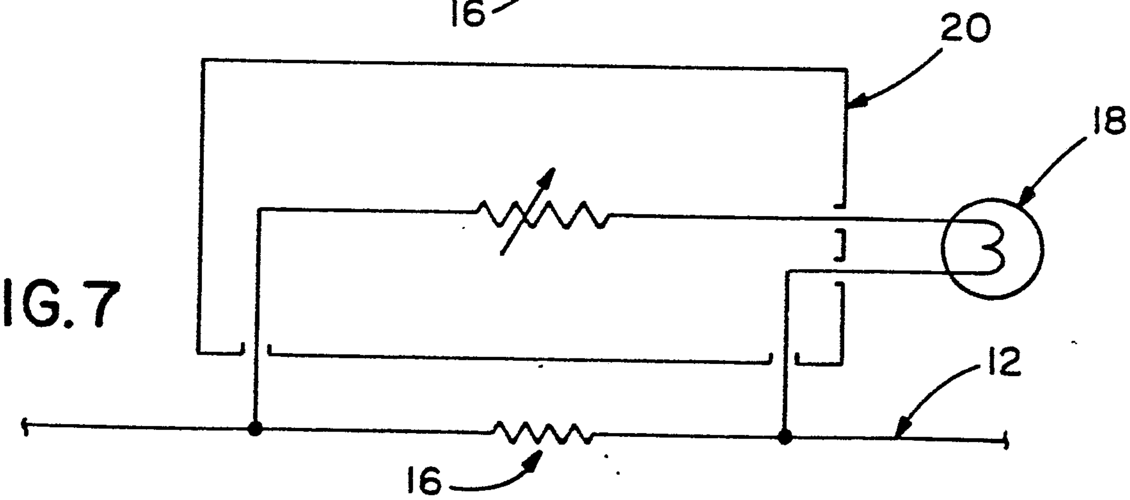


FIG.7



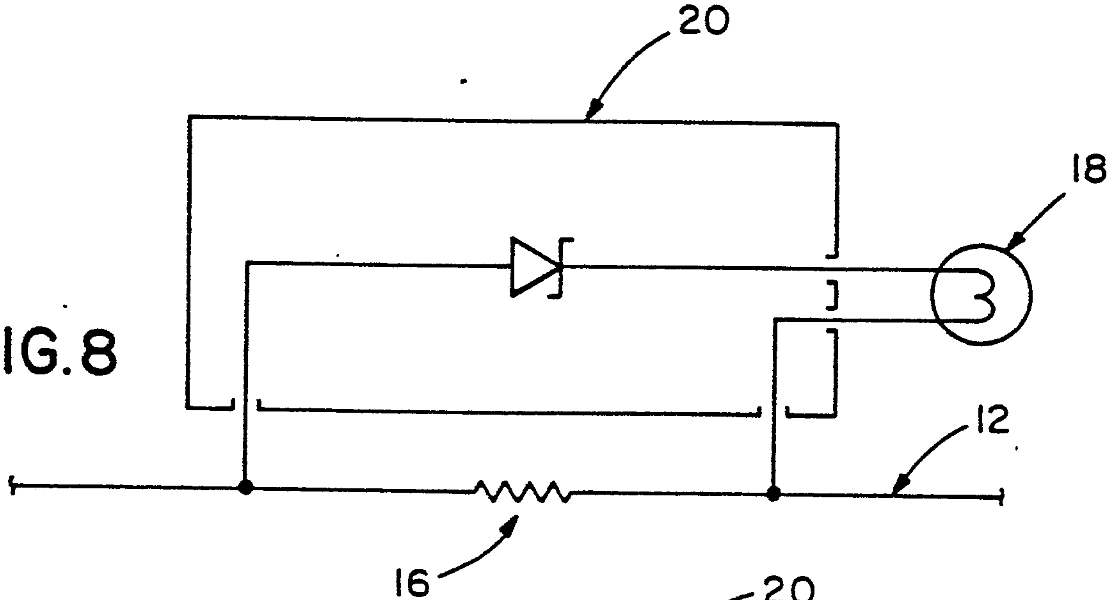


FIG.8

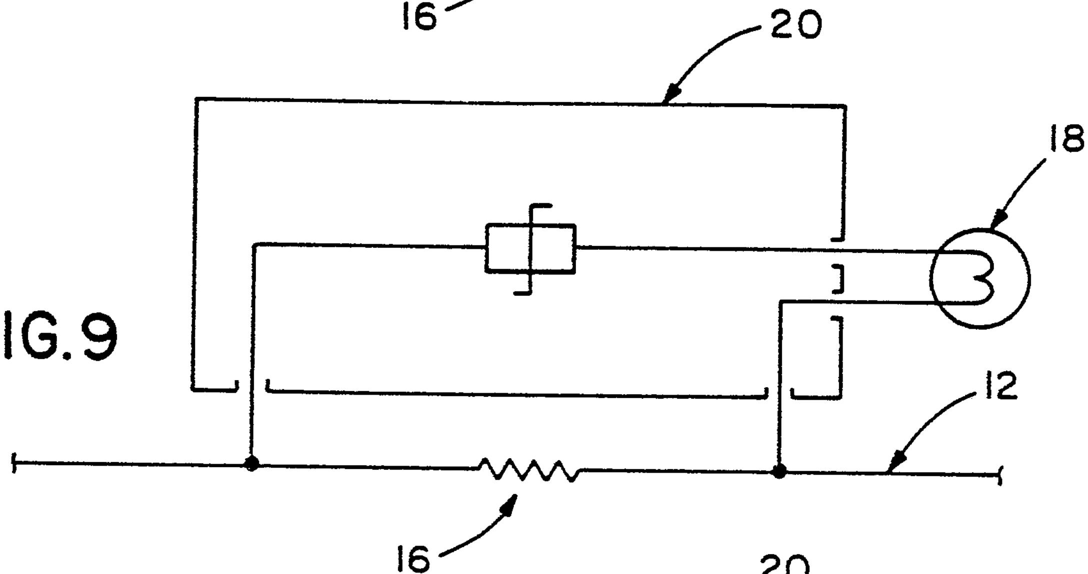


FIG.9

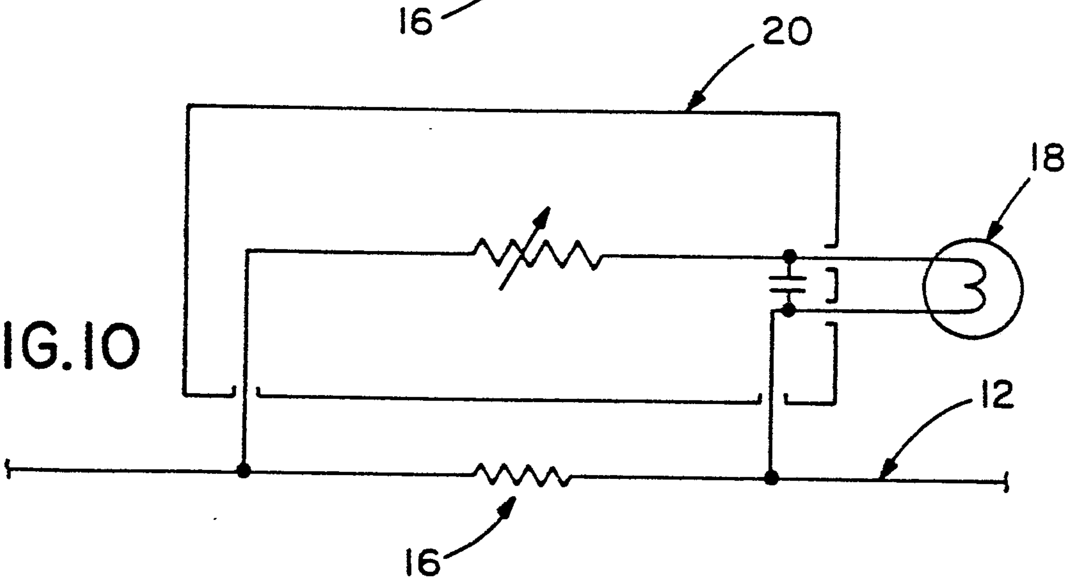


FIG.10