Nov. 14, 1967 A. J. BUFFA ET AL 3,353,059

SERIES MULTIPLE SPARK GAP SWITCH WITH A TRIGGERING TERMINAL

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FIG. 1

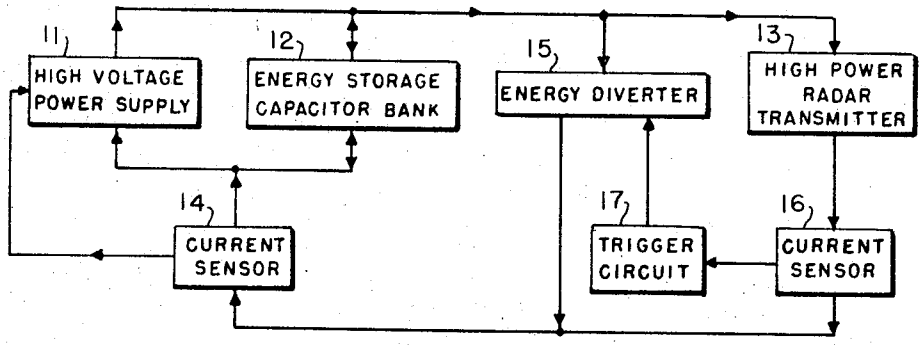


FIG. 2

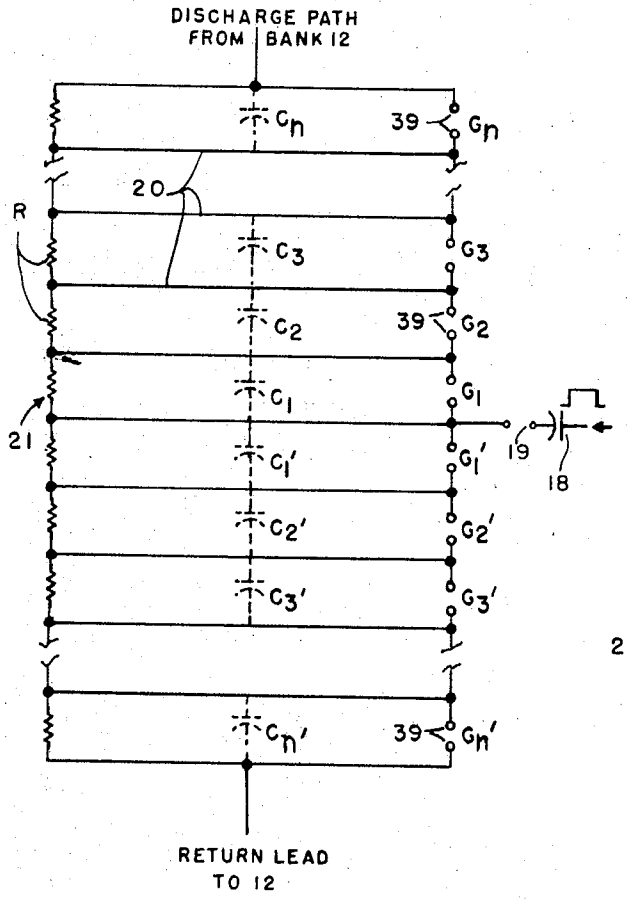
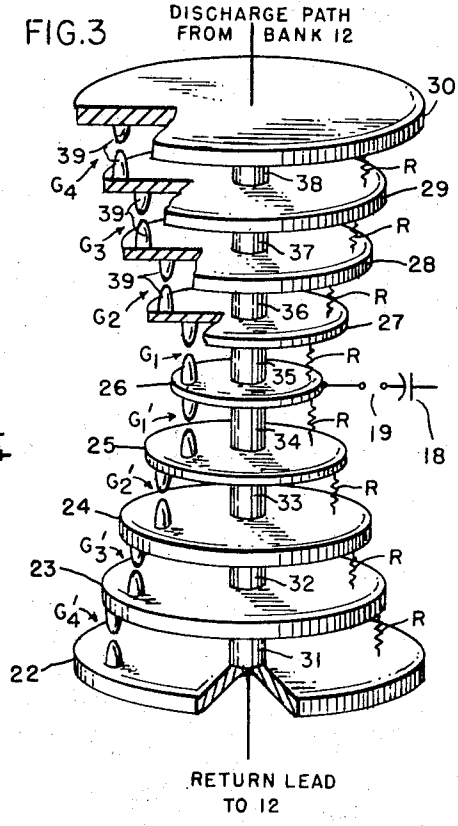


FIG. 3



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SERIES MULTIPLE SPARK GAP SWITCH WITH A TRIGGERING TERMINAL

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ABSTRACT OF THE DISCLOSURE

An energy diverter providing a low resistance path upon receiving a trigger pulse with an even number of series connected resistors and a corresponding number of spark gaps connected in series. An odd number of electrically conductive members connecting members in disk form connecting respective resistors in parallel with corresponding spark gaps with means to feed the trigger pulse to the center connecting member to cause the spark gap to break down thereby providing the low resistance path.

The present invention relates to an electronic circuit protection device and more particularly to a device for diverting energy away from an electronic circuit which may be damaged by such energy.

The utilization of high power transmitters has found a need for the development of devices capable of protecting R-F generators, high-vacuum modulator tubes, and high voltage components in the event of an arc in any of these components. This need is particularly evident in equipment operating at high voltage with large values of stored energy in capacitor banks. The high voltage increases the probability of arcing and the high energy increases the probability of catastrophic destruction of the components.

Of course, most power supplies and capacitor banks are supplied with circuit breakers which will be tripped when an arc is developed in the utilization device. However, circuit breakers are not entirely satisfactory since such devices require a mechanical movement causing their trip time to be relatively long. Also, if the circuit breaker is in the power supply circuit the energy stored in the capacitor bank will still be permitted to discharge through the utilization device, thereby causing damage. On the other hand, if the breaker is incorporated in the capacitor bank circuit, an arc may develop across the breaker or the capacitor bank may be left with a potentially dangerous charge.

This problem is overcome by the present invention by providing a low resistance path or a short circuit for diverting substantially all the energy in the capacitor bank away from the utilization device until the circuit breakers are opened and the capacitor bank is fully discharged. The low resistance path consists of an array of fired spark gaps connected across the utilization device. When an arc is initiated in the utilization device, the resulting increase in power is detected and a trigger pulse is then applied to the spark gap circuit for firing the gaps. Of course, these gaps provide an infinite resistance or an open circuit when the utilization device is operating under normal conditions.

In order for the protection device to successfully protect the utilization device, it must have the following characteristics: (a) rapid firing after application of the trigger pulse, (b) low voltage drop after firing, (c) low energy triggering capability, (d) large range of operating voltage, i.e., the device should be capable of being triggered when there is zero voltage across the utilization device. The need for (a) and (b) alone is evident; the

device must achieve a condition approaching that of a short circuit across the arcing component as rapidly as is possible so as to divert the energy from the arc before any damage has occurred. The diverter obviously must be capable of passing the short circuit current value without being damaged itself. The low triggering requirement is dictated by the usual desire for circuit simplicity and small size, but is also necessary to minimize any pulse signal that may appear in the main circuit during triggering of the spark gaps. Requirement (d) stems from the possible need for circuit operation over a wide voltage range for which protection is desired. This is particularly needed in high-power electron tube processing equipment where arcing is possible at the lower values of plate supply voltage, until seasoning of the electron tube permits stable operation at the higher voltages. There is, however, a need for low-plate-voltage triggering capability to provide for a repetitive firing of the spark gaps and the opening of the circuit breakers, in order to prevent reinitiation of the arc in an electron tube that may have evolved gas during the initial stages of the original arc.

In addition to the characteristics discussed above, the diverter must reliably hold off the desired high voltage without self-triggering induced either by atmospheric effects or normal pulses appearing in the main circuit. A low value of acoustic energy generated by the firing of the spark gaps is also desirable.

While energy diverting circuits providing a low resistance path or short circuit by means of an array of fired spark gaps connected across the utilization device are known, these systems have been complicated in their design and have had to employ such devices as high voltage capacitors from each gap electrode to ground. Simplicity of design, electric circuitry and construction coupled with reliability of operation are necessary for effective use of energy diverting systems.

It is therefore the object of this invention to provide a protection device for diverting energy away from a utilization device, which may be damaged by such energy, and wherein the diverter circuit meets all of the desired requirements discussed above. Other objects and features of the invention will become apparent to those skilled in the art as disclosure is made in the following description of a preferred embodiment of the invention as illustrated in the accompanying drawings in which:

FIGURE 1 shows a block diagram of the invention as it would be used to protect a utilization device;

FIGURE 2 shows a schematic diagram of the details of the diverter circuit; and

FIGURE 3 shows a partially diagrammatic view of an embodiment of the invention.

Referring now to the drawings, wherein like reference characters designate like or corresponding parts throughout the several views, there is shown in FIG. 1, a high voltage power supply **11** for supplying energy storage capacitor bank **12** which in turn is periodically discharged through an oscillator tube such as a high power klystron, magnetron, etc., for generating R-F energy in the conventional high power radar transmitter **13**. A current sensor **14** is also provided in the return path between radar **13** and capacitor bank **12** to measure the rate at which the energy from capacitor bank **12** is being supplied to radar **13**. If an arc should develop in any of the R-F generators, high-vacuum modulator tubes or high-voltage components of radar **13**, the rate of energy supplied will increase to a dangerous level thereby increasing the current in the return path through current sensor **14**. Current sensor **14** will then detect this rise in current and supply a signal to a circuit breaker in power supply **11**. However, the conventional mechanical circuit breakers have a relatively long trip time and are ineffective,

as stated above, for protection of the arcing component. Protection of these components is provided, however, by providing energy diverter **15**, in the system, between capacitor bank **12** and the radar **13** for diverting the energy away from the radar while the circuit breaker in power supply **11** is being tripped. A second circuit sensor **16** will detect the overload or increase in current through radar **13** and energize a trigger circuit **17** which in turn will energize the diverter **15**. In order to avoid damage by a low voltage that is not sufficient to keep the diverter energized, the trigger device should be of the type that sends out a series of trigger pulses which continue for a time long enough for the circuit breakers to trip.

The components of the diverter **15** are shown in detail in FIG. 2. Energy diverter **15** comprises input coupling capacitor **18**, which couples the output of trigger **17** to a sharpening gap **19**, which in turn is connected to the center of a symmetrically balanced series connected set of sparking gaps formed by electrodes **39**. One half of the set of sparking gaps, G_1, G_2, G_3 . . . G_n, is connected from the sharpening gap **19** to the discharge path from bank **12**. The other half of the set of sparking gaps, G_1', G_2', G_3' . . . G_n' is connected from the sharpening gap **19** to the return lead to capacitor **12**. The set is balanced by making all of the gap openings equal in size and the capacitance values of corresponding gaps in each half of the array equal, i.e., $C_1=C_1'$, $C_2=C_2'$, $C_3=C_3'$ . . . $C_n=C_n'$. A voltage divider **21**, consisting of a plurality of series connected resistors, R, is connected between the discharge path from capacitor bank **12** and the return lead to bank **12**. A plurality of electrically conductive members **20** connect equal values of resistors R in parallel with each of the sparking gaps G_n . . . G_n'. The capacitances of the gaps and their accompanying connecting members **20** are shown in phantom on the schematic diagram, that is, the capacitance and its accompanying connecting members of G_1 is shown in phantom as C_1, that of G_1' and its accompanying connecting members is shown in phantom as C_1'; etc. The voltage divider **21** acts to distribute the voltage between the high voltage side of radar **13** (FIG. 1) and the return lead to capacitor bank **12** eventually across each of the spark gaps. The firing of the diverter **15** is initiated by a high-voltage pulse from trigger circuit **17** (FIG. 1). Capacitor **18**, which is merely a coupling capacitor has a relatively high capacitance compared to the capacitance of the spark gaps and their accompanying connecting members, and will therefore contain only a negligible amount of the pulse voltage during operation. The sharpening gap **19** is designed to have a very low interelectrode capacitance and, accordingly, all the voltage appears across it prior to firing, thus, providing a high-voltage pulse with an exceptionally steep wave form to the center of the spark gap array. The interelectrode capacitances of the spark gaps and their accompanying connecting members are designed to provide a triggering sequence, wherein the spark gaps will break down one after the other from the center of the set toward its ends when the trigger pulse is presented to the center of the spark gap array. A preferred design is to have all of the interelectrode gap capacitances essentially equal with the exception of the outermost gaps, G_n and G_n' which are made larger, usually twice the capacitance of one of the inner gaps. Specifically, when the trigger pulse is presented to the set of spark gaps, the voltage of the trigger will attempt to distribute among the spark gaps inversely proportional to the capacitances of the gaps. However, the impact of the sharply rising voltage of the pulse is initially loaded on the two spark gaps G_1, G_1' closest to the center of the spark gap set. The air in the spark gaps, which have been ionized by some stray radiation from the atmosphere, will break down due to this high voltage, causing a spark across the gaps G_1 and G_1'. After the spark is initiated the voltage across the gaps will drop to a relatively negligible amount and all the voltage from the trigger will tend to redistribute among the gaps that have not sparked, with the unsparked gap in each half of the set nearest to the center receiving the main load of the trigger pulse and thus breaking down next. This sequence will continue until the outermost spark gaps receive the full trigger voltage and fire this providing the desired low resistance path through the gaps from the high voltage side to the return lead. The high voltage across the gaps will usually be sufficient to keep the gaps firing, even if the trigger pulse were removed. An advantage of making most of the gaps approximately equal is that even if the initial gap fires with a marginal trigger voltage, each trigger will receive a much higher voltage and fires more rapidly. The sequence of events from the sharpening gap breakdown to complete breakdown of the energy diverter is rapid; for example, the firing time is less than 100 nanoseconds when 8 spark gaps are employed.

Referring now to FIG. 3, there is shown a physical embodiment of the invention which, in addition to having the advantages of the present invention, is simple to construct and has excellent inherent high-voltage shielding properties. For reasons of simplicity an eight gap array is described but it will be obvious to anyone skilled in the art that the number of gaps may be increased or decreased without departing from the scope of the invention. A plurality of electrically conducting circular discs **22**, **23**, **24**, **25**, **26**, **27**, **28**, **29** and **30** are mounted parallel to each other by means of a plurality of equal length cylinders, **31**, **32**, **33**, **34**, **35**, **36**, **37** and **38** made of a rigid insulating material. The discs are arranged with disc **26**, the center disc, having the smallest diameter and discs positioned on both sides of disc **26** having increasingly larger diameters as their respective positions away from the center increases, with the discs having equal distances from the center having equal diameters. These disc shaped geometry with increasingly larger dimensions from the center is particularly effective for high voltage uses since this arrangement gives effective prevention of corona discharge while allowing the outermost gaps to have the largest capacitance. As is well known, corona discharge is brought about as a result of the ionization of the gas surrounding a conductor and occurs when the potential gradient exceeds a certain value but is not sufficient to cause sparking. When used in a circuit of the type shown in FIG. 1, disc **30** would be connected to the discharge path from bank **12**, disc **22** would be connected to the return lead to **12** and the trigger signal would be directed through capacitor **18** and sharpening gap **19** to disc **26**. These discs correspond to the electrically conductive members **20** in FIG. 2. A voltage dividing resistor, R, is connected between each pair of opposing sides of adjacent discs thus forming a voltage divider for the voltage from the discharge bank **12** and the return lead to bank **12**. Elecetrodes **39** are mounted in opposition on the opposing sides of adjacent discs so as to form spark gaps, G_1, G_2, G_3, G_4, G_1', G_2', G_3', and G_4', said gaps being provided with equal openings. The geometry of the electrodes is varied in accordance with well known principles to provide the desired capacitance at the gaps.

Obviously many modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood, that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A device for selectively providing a low resistance path between points at different electrical potential upon receiving a trigger pulse comprising: an even number of resistors connected in series, a corresponding number of spark gaps connected in series, an odd number of electrically conductive members including a center member

connecting respective resistors in parallel with corresponding spark gaps, and means connected to said center electrical member for feeding said trigger pulse to said center conductive member.

2. The device of claim 1 and wherein the number of spark gaps is at least four and the capacitance of each of the two spark gaps outermost from the center of said series of spark gaps is larger than the capacitance of each of the spark gaps between said two outermost spark gaps.

3. The device of claim 1 and wherein each of the electrically conductive members comprises a circular disc.

4. The device of claim 3 and wherein each spark gap has two opposed electrodes and said gaps are connected in series by mounting said electrodes on opposing faces of adjacent discs.

5. The device of claim 4 including rigid insulating support means connected between adjacent discs for supporting said discs parallel to each other.

6. The device of claim 5 and wherein the diameter of the center disc is the smallest and the diameter of the discs increase as their position from the center increases.

7. The device of claim 6 and wherein the number of spark gaps is at least four and the capacitance of each of the two spark gaps outermost from the center of said series of spark gaps is larger than the capacitance of each of the spark gaps between said two outermost spark gaps.

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