

July 12, 1966

B. BERGHAUS ETAL

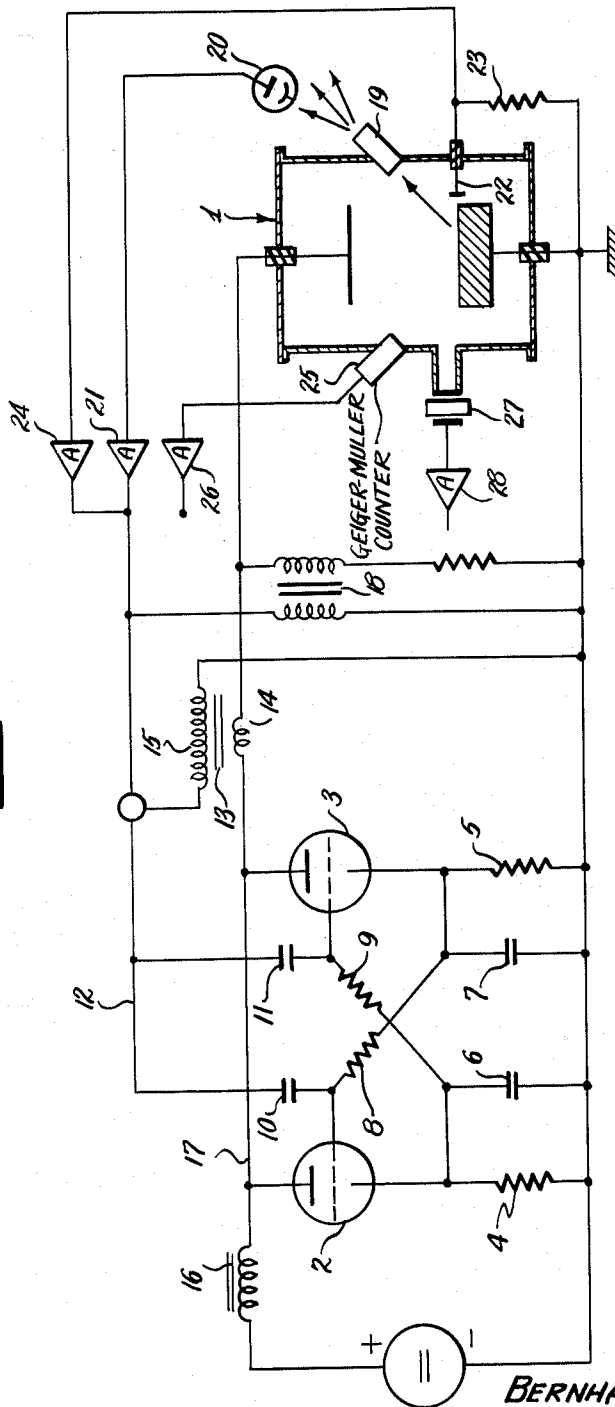
3,260,892

DEVICE FOR AVOIDANCE OF IRREGULAR CHANGES OF THE DISCHARGE
CONDITION FOR DISCHARGE VESSELS PROVIDED FOR HIGH
CURRENT GLOW DISCHARGES

Filed Nov. 29, 1962

2 Sheets-Sheet 1

Fig. 1.



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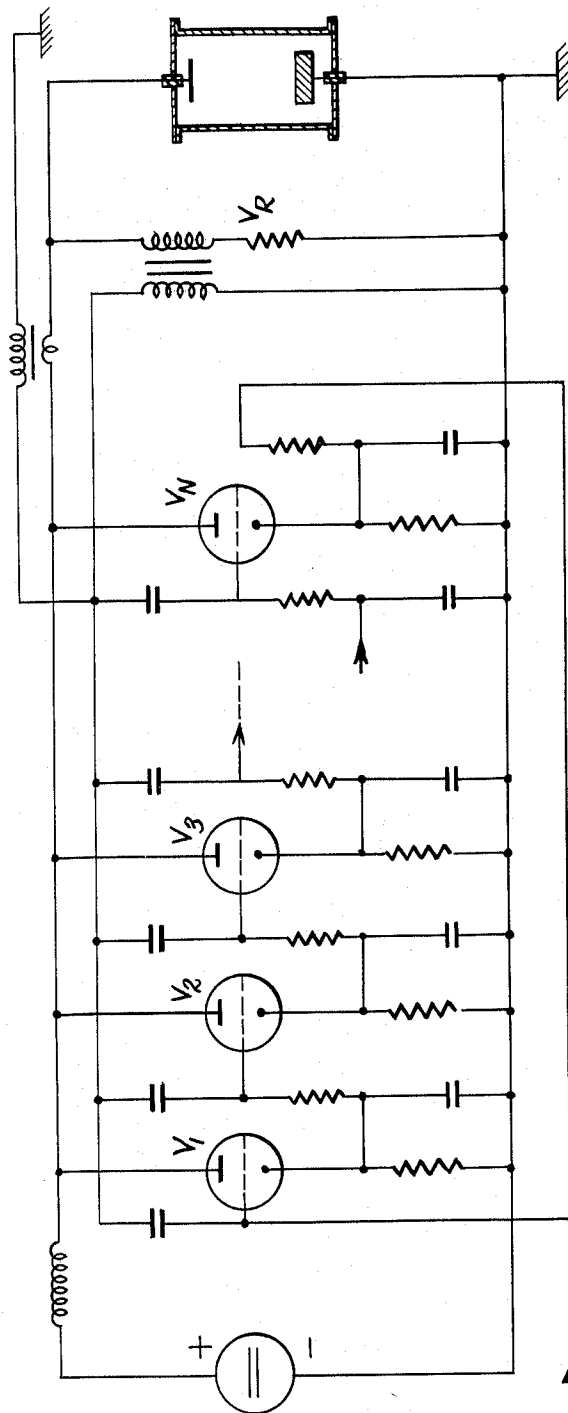


Fig. 2.

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DEVICE FOR AVOIDANCE OF IRREGULAR CHANGES OF THE DISCHARGE CONDITION FOR DISCHARGE VESSELS PROVIDED FOR HIGH CURRENT GLOW DISCHARGES

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Filed Nov. 29, 1962, Ser. No. 240,910

Claims priority, application Switzerland, Dec. 1, 1961, 13,973/61

26 Claims. (Cl. 315—306)

This invention relates to a device for carrying out the method described in the copending application of Bernhard Berghaus, Serial No. 50,276, filed August 17, 1960, now U.S. Patent No. 3,181,029, for stabilizing the high current gas and glow discharges by means of reduction of the working voltage and thus reduction of the energy supply to the discharge vessel in the event of irregular changes of the discharge condition.

According to the application referred to the voltage on the discharge vessel is reduced prior to the formation of a spark discharge or of an arc and within such a short time that a spark discharge or arc cannot occur. Such a voltage reduction is possible for instance by means of a resistance switched in parallel to the discharge vessel. But for effecting an efficient voltage reduction by means of switching a resistance in parallel to the discharge vessel, the current flowing over this resistance must be at least of the same order, preferably however essentially greater than the discharge current. Therefore, considerable difficulties arise in switching off this resistance after it has been on, which is easy to understand by considering the fact that the necessary voltage reduction could be achieved by switching off the discharge circuit, where the current is lower or at most of the same order. Such a switching off the discharge circuit however is difficult because the current coming from the generator has as a rule an inductive component, which cannot be changed within a short time. Therefore, it is not practical to effect the necessary voltage reduction by switching a resistance in parallel to the discharge vessel. Rather a circuit element should be switched in parallel and which is capable of effecting the necessary voltage reduction immediately and to let pass no more current on the other side after a certain time interval. For this purpose a capacitor is well suitable. However, by using a capacitor for the voltage reduction a new problem arises, namely the question of operating readiness.

A capacitor switched in parallel to the energy supply line effects the desired voltage reduction from the moment of switching in parallel and maintains this voltage reduction over a certain time sufficient for removal of the cause of the irregular changes, if the charging time constant is proportioned appropriately. At the end of this time, however, the capacitor is charged to the voltage on the discharge vessel and must now be discharged in order to be ready for a further cycle of operation.

The discharging of a capacitor, however, cannot be carried out within a time as short as one likes, because a certain charge quantity must flow down and, therefore, the discharging current must be high for short discharging times. With frequent flow of high discharge currents, however, the life time of the capacitor is quite limited, because with very high discharge currents mechanical forces are effective within the capacitor, which results in a mechanical destruction of the capacitor.

Therefore, a certain time is necessary for discharging of the capacitor, which should be chosen at least in the order of the charging time or longer. However, if during this discharging time of the capacitor a new irregular

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change of the discharge condition appears in the discharge vessel, the capacitor is not ready for operation and, therefore, the formation of an arc or a spark discharge is inevitable.

Therefore, it is an object of the invention to provide a device, with which also in the case of irregular changes of the energy supply to the discharge vessel, it is possible within a time less than the formation time of these changes, to function through a full cycle and wherein the circuit elements are not overloaded so that long life of these circuit elements is assured.

According to the present invention this is accomplished by a device for preventing irregular changes of the discharge condition, more particularly for the prevention of arcs in the beginning of their rise and even before their formation, for discharge vessels provided for high current glow discharges. The invention proposes a shunting system continuously ready for operation provided and with a plural number of capacitors connected with a switching system, as shunt elements to the discharge vessel, and further with control means actuated by irregular changes of the discharge condition for controlling the switching system, and which prepares the next capacitor for current input, when a first capacitor takes up current.

Devices according to the invention preferably are used for discharge vessels designed for a discharge power of more than 10 kilowatts, more particularly of more than 30 kilowatts, especially advantageous are devices according to the invention for discharge vessels with a discharge power of more than 50 kilowatts, and even more particularly, however, for a discharge power of more than 100 kilowatts.

Preferably such a device for short time automatic reductions of energy supply to discharge vessels in the event of irregular changes of the discharge condition is provided with a short-time current limiting element, preferably an inductance, connected in the supply line and with at least two capacitors switchable by means of controllable switching elements in parallel to the discharge vessel, which are proportioned so that by switching one of the capacitors in parallel to the discharge vessel the discharge power in the discharge vessel is substantially reduced during charging of the capacitor, preferably so the discharge is extinguished for a short time, whereby in the manner of multistable multivibrators the switching elements are connected with a common control line and are connected together so that, at any time, only one switching element is switchable on and prepares the next switching element for operation. Thus, at all times at least one switching element is prepared for switching on and a succeeding one is readied whereby it is possible to actuate the latter within a time smaller than the formation time of an arc or of a spark discharge. Preferably this device is further provided with control means acting upon a common control line and actuated by irregular changes of the discharge condition within a time interval substantially smaller than the formation time of an arc or of a spark discharge, and further with means for discharging the capacitors, which means are actuated at time when the attached switching elements are switched off.

The switching elements are preferably cumulative grid gas discharge tubes, gas discharge tubes with ignition pins, or controllable semiconductors, especially transistors. The passage resistance of these switching elements should be lower, preferably substantially lower than the resistance imposed by the discharge in the discharge vessel. Preferably the switching elements are so arranged and connected so that the switching element switched on remains in this condition until the next irregular change of the discharge condition.

The capacities of the capacitors preferably are such that their charging time constant is greater than the re-

moving time of the discharge in the discharge vessel, at which the charging time constant of the capacitors preferably should lie between two and five times the maximum possible removal time of the discharge in the discharge vessel. Preferably a resistance is connected in parallel to each capacitor as means for discharging the same and series connections of the so formed R-C-members with the respective attached switching elements are connected in parallel to the discharge vessel. The resistances connected in parallel to the capacitors preferably should be higher, preferably substantially higher than the passage resistances of the respective attached switching elements. If the switching element switched on at one time remains switched on until the next irregular change of the discharge condition, for avoidance of energy losses, it is expedient to proportion the resistances connected in parallel to the capacitors so that they are at least five times the resistance formed by the discharge in the discharge vessel. Generally the resistances R connected in parallel to the capacitors provide such passage resistances R_d , that with a working voltage U and a working current I of the discharge vessel the ratio $1:(1+R_d/R) \cdot (1+IR_d/U)$ is greater than the voltage reduction $\Delta U/U$ at least necessary for extinguishing the discharge in the discharge vessel.

According to one preferred embodiment of the invention the device may be built up so that N capacitors are switchable in parallel to the discharge vessel each by means of an attached controllable switching element, and forming a closed chain with N links each containing a capacitor and the attached switching element. The single links are connected with the following links respectively so that switching on of the switching elements ensues in the sequence of the links so that each capacitor is switched in parallel to the discharge vessel only at time after passing N irregular changes of the discharge condition. In this way it is possible to provide for a sufficient time for discharging the capacitors, whereby the life time of the capacitors is extended considerably. Therefore, the number N of links preferably is chosen so great that the capacitors are discharged completely within the interval between switching on the attached switching elements, through discharging resistances connected in parallel to the capacitors.

Of course it is also possible and for certain cases very advantageous too, that an additional controllable switching element be connected in parallel to each capacitor as a means for discharging, which additional switching element is switched on during the time when the controllable switching element attached to the capacitor is switched off. With such additional switching elements means may be provided which effect switching on the additional controllable switching element not before the switching element attached to the capacitor is in ready condition. This has the advantage that the capacitor is discharged at first over a resistance connected in parallel, and that only a residual charge remaining in the capacitor flows through the additional controllable switching element so that too high discharge currents are avoided and further additional switching element with relatively low maximum passage currents may be used.

As control means preferably an element connected in the energy supply line to the discharge vessel and, therefore, influenced by the discharge current is provided. Preferably this element is a transformer, the primary winding of which is connected in the energy supply line between the discharge vessel and the capacitors switchable in parallel to the discharge vessel and, therefore, is traversed only by the discharge current of the discharge vessel, and the secondary winding of which has such a great number of turns that an irregular change of the discharge current induces an impulse in the secondary winding sufficient for controlling the switching system, for which the secondary winding is connected with the switching system.

Further as additional, or alternatively as sole, control

means an element connected in parallel to the discharge vessel and, therefore, influenced by the discharge voltage may be provided. Preferably this element is likewise a transformer, the primary winding of which is connected in parallel to the discharge vessel, and the secondary winding of which is connected to the common control line, and the transformation ratio of which is chosen so that an irregular change of the discharge voltage induce an impulse in the secondary winding sufficient for controlling the switching system.

Further, as control means, a member sensitive to spectral changes of the light in the discharge vessel may be used, which converts these changes into control pulses. Further advantageous results may be achieved by using a member sensitive to pressure as a control means, which member is connected with the discharge chamber and supplies a control pulse by a pressure change in the discharge vessel, or by using as control means a member arranged near the mean electrode in the discharge vessel and being sensitive to secondary emission of this electrode, or by using as control means a member sensitive to electromagnetic waves produced by the discharge and supplying control pulses by irregular changes of those waves. All said control means may be used either alone or in combination with other of the said control means.

The invention is further described by means of the accompanying drawings showing an embodiment of the invention and wherein:

FIG. 1 shows a device according to the invention with two capacitors and two controllable switching elements for a discharge vessel supplied with direct current, and;

FIG. 2 illustrates a device according to the invention with N capacitors and N controllable switching elements for a discharge vessel supplied with direct current.

In FIG. 1 the energy supply to the discharge vessel 1 is to be interrupted for a short time, when irregular changes of the discharge condition appear, for instance in the event of conditions leading to the formation of an arc. The imminent formation of an arc for instance is signalled by a strong rise of the current and by a fall of the discharge voltage in the discharge vessel.

For the purpose of this short time breaking two gas discharge tubes 2 and 3, preferably inert gas thyratrons, are connected in parallel to the discharge vessel 1 and into the cathode lines of which working resistances 4 and 5 are connected. Capacitors 6 and 7 are respectively connected in parallel to each of these working resistances between the negative line and the cathode of the respective tube 2 or 3.

Protective resistance 8 and 9 are respectively to the control grid of one discharge tube and the cathode of the other. Further the control grids of the discharge tubes are connected, through the capacitors 10 and 11, with a common control line 12.

This common control line 12 is connected, in the embodiment shown, with a plural number of control devices, the first of which is shown at 13 and will be discussed first. This control device consists of a transformer connected as a current transformer, the primary winding 14 of which is connected from the supply line to an electrode of the discharge vessel 1. One end of the secondary winding 15 of this current transformer is connected to the negative line, while the other end is connected to the common control line 12.

Also in the positive supply line an inductance 16 is provided, which prevents a sudden rise of current and permits only a relatively low rate current rise.

For explanation of the operation of the illustrated circuit, first assume that the discharge vessel works under normal conditions so that a constant current flows through the primary winding of the transformer 13. Now if the discharge current rises suddenly as a result of an irregular change of the discharge condition in chamber 1, then the secondary winding 15 of the transformer 13 develops a voltage by induction, the magnitude of which is de-

pendent on the rising rate and on the value of the primary current and further on the transformation ratio of the transformer 13. Further it shall be supposed, that the discharge tube 2 is thus ignited, so that a small current flows through the working resistance 4 and through the discharge tube 2. Since the control grid of the discharge tube 3 is connected to the cathode of the discharge tube 2 through the resistance 9, this control grid of the discharge tube 3 is biased positively and therefore the discharge tube 3 is prepared for ignition. The voltage impulse induced in the secondary winding 15 of the transformer 13 is therefore conducted over the common control line 12 and to the capacitor 11 and the discharge tube 3, prepared for ignition, so that the capacitor 7 is thus switched in parallel to the discharge vessel through the resistance of the discharge tube 3. If this resistance is negligibly low, the capacitor 7, in the first moment, acts as a short circuit for the energy supply line. Since the current flowing through the inductance 16 cannot rise immediately, the whole current flows into the capacitor 7 and the current flowing to the discharge vessel becomes zero at this moment. Further also the voltage of the positive supply line 17 becomes zero in the first moment, so that the discharge tube 2 is extinguished. If the resistance of the discharge tube is not negligibly low in comparison with the resistance represented by the discharge in the discharge vessel, the currents through the discharge tube 3 and the discharge vessel 1 are distributed in proportion to their conductances, at the moment of ignition of the discharge tube 3. The resistances of the discharge tubes 2 and 3 must be proportioned so that by switching on one of these discharge tubes the voltage reduction is at least so great that at least the discharge in the other discharge tube, preferably however also in the discharge vessel, is extinguished. Therefore, after ignition of the discharge tube 3 the discharge in the discharge tube 2 and in the discharge vessel 1 is extinguished, and the capacitor 7 is charged through the discharge tube 3. The charging time constant is so chosen that the causes of the irregular change of the discharge condition in the discharge vessel 1 are removed. Upon charging the capacitor 7 a voltage rise results on the energy supply line 17, so that the discharge vessel 1 is ignited again at the moment of reaching the ignition voltage. After capacitor 7 is fully charged the discharge tube 3 remains switched on and the voltage across the capacitor 7 reaches the value of the voltage appearing across the resistance 5.

It is to be noted that the inductance 16 offers advantages in two ways. On the one hand the inductance 16 insures that the current cannot rise at the moment of switching on the discharge tube 3 and that therefore the entire current flows into the capacitor 7 and the discharge current is broken thereby. On the other hand the inductance 16 simultaneously prevents overloading the energy supply device at the moment of short circuiting of the energy supply line by switching in the capacitor 7 in parallel with vessel 1.

When the capacitor 7 is charged through the discharge tube 3, the normal voltage and the normal current appear again in the discharge vessel 1. It is to be noted that extinguishing of the discharge in the discharge vessel 1 is not absolutely necessary, the discharge current may be reduced only to such a degree that the causes of the irregular changes of the discharge condition are removed. In this case the current to the discharge vessel rises again upon charging the capacitor 7. After reaching this stable condition the discharge tube 2 is prepared for ignition by the voltage at resistance 5, so that upon arrival of a control pulse caused by a new irregular change of the discharge condition, the discharge tube 2 is switched on, and capacitor 6 discharged in the meantime through the resistance 4 and forms a short circuit across the energy supply line.

Upon each actuation of the control device 13 as a result of an irregular rise of the current in the discharge

vessel, the discharge tubes 2 and 3 ignite alternately and reduce the current flowing through the discharge vessel 1 so much that during the charging time of their respective capacitors 6 and 7, the cause of the irregular change of the discharge condition is removed.

Instead of the control device influenced by the discharge current, or in addition thereto, a further control device influenced by the discharge voltage may be provided, which produces a control pulse by irregular voltage fall of the voltage across the discharge vessel. Preferably this further control device influenced by the discharge voltage is a transformer like the transformer 18 in FIG. 1, the primary winding of which is connected in parallel to the discharge vessel, and the secondary winding of which is connected on one side to the negative line and on the other side to the common control line 12, and at which the secondary winding is polarized so that a voltage fall at the discharge vessel effects a positive impulse on the common control line 12.

Besides these direct electrical effects of irregular changes of the discharge condition, also other physical effects appearing with such irregular changes are usable as control criteria. In FIG. 1 some of these possibilities are shown. It must be emphasized however that from the shown control devices generally only one or perhaps two are necessary. The control device consisting of the monochromator 19, the photocell 20 and the amplifier 21 for example is sensitive to the spectral composition of the light emanating from the discharge and produces a control pulse on the common control line 12 upon a sudden change of this spectral composition. Further it is also possible to use the secondary emission of the treated workpiece as a control criterion and to provide an auxiliary electrode 22 near the workpiece to be treated for measuring this secondary emission, which auxiliary electrode is connected to the input of the direct current amplifier 24 and over the high ohmic resistance 23 with ground. Upon a sudden change of the potential of this auxiliary electrode 22 the amplifier 24 delivers a control pulse to the common control line 12. Also the radioactivity of the gas in the discharge vessel is usable as control criterion. For this purpose the Geiger-Muller counter 25 may be provided, the output pulses of which are delivered into the integrating amplifier 26, which delivers a control pulse to the common control line 12 upon a sudden change of cadence frequency of the counter or by transgression of a certain cadence frequency. Further also sudden changes of the gas pressure, resulting from gas eruptions from the treated workpiece, are usable as control criteria, and by converting these pressure changes by means of the piezoelectric crystal 27 into electrical impulses, the latter may be amplified by means of the amplifier 28 and then are conducted to the common control line 12. Further changes of the pH-value and changes of the conductance of the gas within the discharge vessel and electromagnetic waves produced by the discharge may be used as control criteria.

In cases where the resistances in the cathode lines of the discharge tubes must be so high that discharging the capacitors switchable in parallel to the discharge vessel over these resistances takes up too much time, or in the case of exceeding the permissible maximum load on the discharge tubes, instead of the bistable trigger circuit with two discharge tubes and two capacitors switchable in parallel to the discharge vessel as shown in FIG. 1, a multistable trigger circuit with N discharge tubes and N capacitors switchable in parallel to the discharge vessel as shown in FIG. 2 may be used. In the circuit shown in FIG. 2 the discharge tubes $V_1 \dots V_N$ are switched on in the sequence $V_1, V_2, V_3, \dots V_N, V_1, V_2, \dots$ so that each discharge tube is switched on again only after N irregular changes of the discharge condition and so that each capacitor C is switched again in parallel to the discharge vessel for voltage reduction only after N irregular changes of the discharge condition. By such a construc-

tion of the device according to the invention a considerable reduction of mean load of the single discharge tubes is effected and also complete discharge of the capacitors is accomplished within the intervals of time between switching on their associated discharge tubes. Further, in such a construction it is possible to choose the resistances R so high that the loss current flowing over these resistances becomes negligible in comparison with the discharge current through the discharge vessel.

It is to be understood that the circuits shown in the drawings are only illustrative of embodiments of devices embodying the invention, and that the invention by no means is restricted to these circuits.

We claim:

1. A device for controlling a high current glow discharge between electrodes in a vessel wherein operating voltage is impressed on said electrodes and wherein changes in the character of said discharge portend formation of an arc or spark discharge, comprising: a plurality of means for shunting said electrodes, said means each comprising a capacitor and switching means for placing the capacitor in shunting relation to said electrodes; control means for sensing said changes in the character of said discharge and effecting operation of said switching means; and means responsive to shunt current in one of said shunting means for conditioning another shunting means for subsequent operation.

2. A device as defined in claim 1 wherein said shunting means are capable of carrying, for a short time, energy in excess of 10 kilowatts.

3. A device as defined in claim 1 wherein said shunting means are capable of carrying, for a short time, energy in excess of 30 kilowatts.

4. A device as defined in claim 1 wherein said shunting means are capable of carrying, for a short time, energy in excess of 50 kilowatts.

5. A device as defined in claim 1 wherein said shunting means are capable of carrying, for a short time, energy in excess of 100 kilowatts.

6. A device as defined in claim 1 including power supply lines connected to said electrodes; an inductance in one of said lines; said shunting means being connected across said supply lines whereby switching of one of said capacitor to shunt said electrodes between said electrodes and inductance capacitor-charging current from said supply lines to substantially extinguish said discharge for a short interval of time; said switching means being connected to a common control line; said control means effecting operation of said switching means through said common control line; and means for discharging each capacitor in response to actuation of its switching means to switch said capacitor out of operative shunt relation to said electrodes.

7. A device as defined in claim 6 wherein said switching means comprise controllable gas discharge tubes.

8. A device as defined in claim 7 wherein said gas discharge tubes are cumulative grid tubes.

9. A device as defined in claim 7 wherein said gas discharge tubes are controllable by ignition pulses.

10. A device as defined in claim 1 wherein said switching means comprise semiconductor devices.

11. A device as defined in claim 1 wherein said shunting means are of an impedance less than the resistance of said discharge between said electrodes.

12. A device as defined in claim 6 wherein said switching means remain in actuated condition until a subsequent change in the character of said discharge.

13. A device as defined in claim 1 wherein the capacity of each of said capacitors is such that its charging time

constant is greater than the time necessary to substantially extinguish said discharge.

14. A device as defined in claim 13 wherein said charging time constant is from two to five times the maximum discharge extinguishing time.

15. A device as defined in claim 1 including a resistor connected in parallel with each capacitor.

16. A device as defined in claim 15 wherein the resistance of each of said resistors is substantially greater than the resistance of its associated switching means.

17. A device as defined in claim 16 wherein the resistance of each of said resistors is at least five times the resistance of the discharge between said electrodes.

18. A device as defined in claim 15 wherein the ratio $1:(1+R_d/R) \cdot (1+IR_d/U)$ is greater than the voltage reduction $\Delta U/U$ necessary to extinguish the discharge between said electrodes, R being the resistance of a resistor, R_d being the resistance of a switching means, I being the working current, and U being the working voltage.

19. A device as defined in claim 6 including a controllable switching element connected in parallel across each capacitor for discharging the same and being arranged to be switched on when its associated switching means is off.

20. A device as defined in claim 1 including energy supply lines connected to said electrodes; said control means comprising a step-up transformer, the primary winding of which is in one of said supply lines between said electrodes and said shunting means; the secondary winding of said transformer being connected to said switching means whereby a change in current to said electrodes produces a control pulse in said secondary winding for actuating said switching means.

21. A device as defined in claim 1 wherein said control means comprises a control element connected in parallel with said electrodes.

22. A device as defined in claim 21 wherein said control element is a transformer, the primary winding of which is connected in parallel with said electrodes; the secondary winding of said transformer being connected to said switching means whereby a change in current to said electrodes produces a control pulse in said secondary winding for actuating said switching means.

23. A device as defined in claim 1 wherein said control means is a member sensitive to spectral changes in the light produced by said discharge and which produces an electrical pulse in response to such change.

24. A device as defined in claim 1 wherein said control means is a pressure responsive member capable of producing an electrical pulse in response to a change in pressure in said vessel.

25. A device as defined in claim 1 wherein said control means is a member sensitive to secondary emission from one of said electrodes, said member being positioned adjacent said electrode.

26. A device as defined in claim 1 wherein said control means is a member sensitive to electromagnetic waves produced by said discharge.

References Cited by the Examiner

UNITED STATES PATENTS

2,369,678	2/1945	McWhirter et al.	340—253
2,445,171	7/1948	Graff-Baker	315—307 X

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