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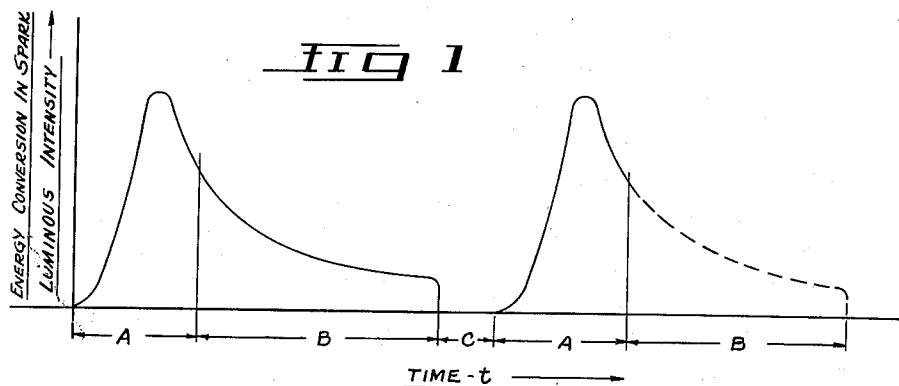
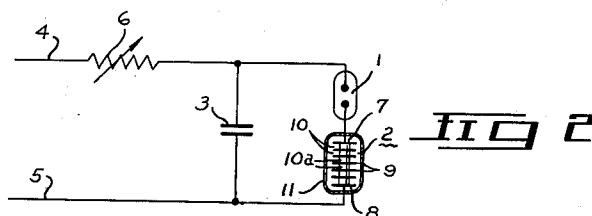
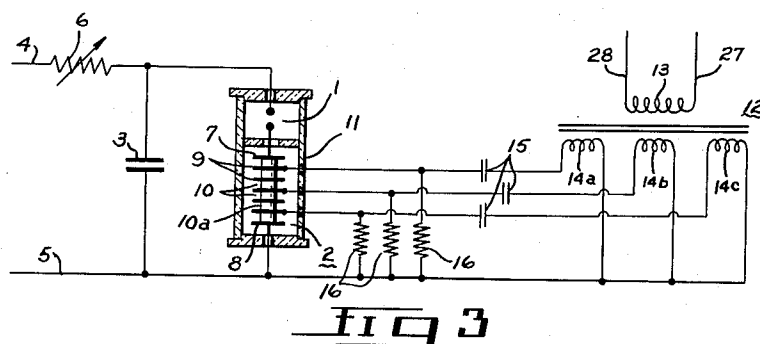
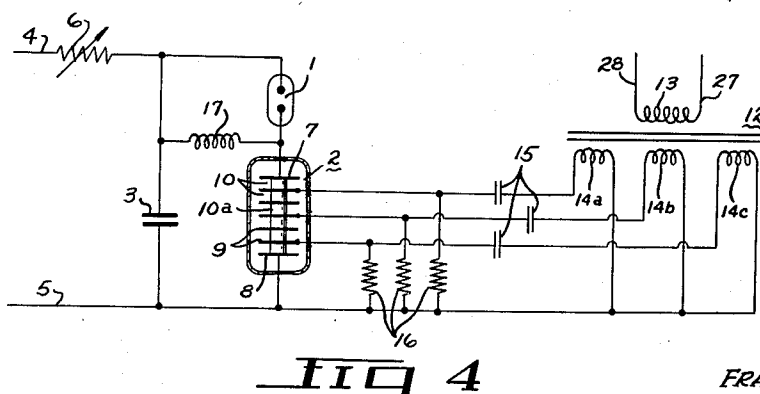
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2,965,807

LAMP FOR EMITTING LIGHT FLASHES OF EXTREMELY SHORT DURATION

Filed March 21, 1956

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

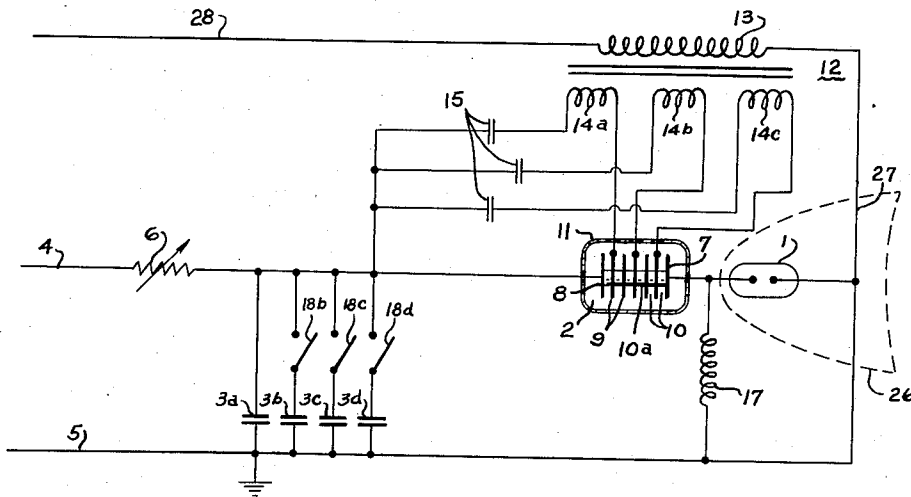


FIG 5

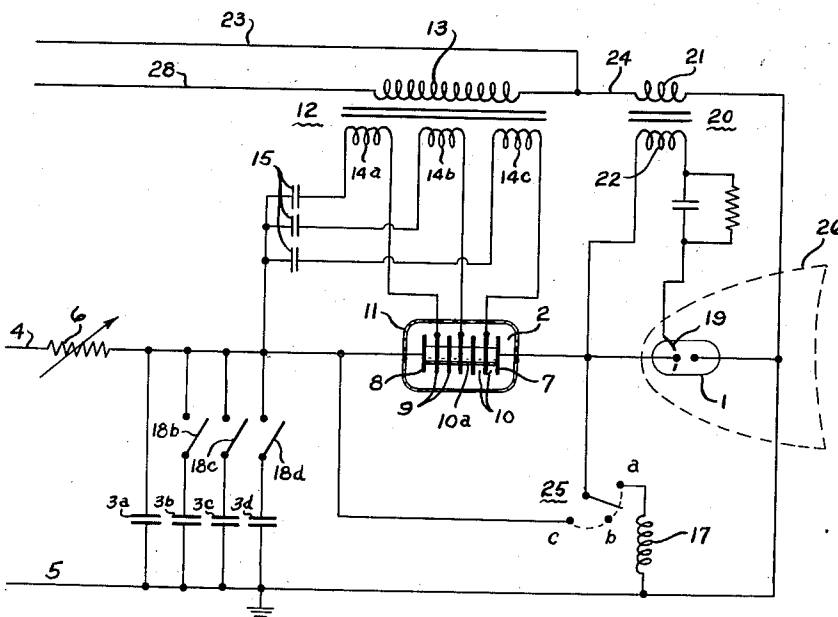


FIG 6

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2,965,807

LAMP FOR EMITTING LIGHT FLASHES OF EXTREMELY SHORT DURATION

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This invention relates to lamps for emitting electric spark-discharge light flashes of microsecond duration, and is particularly concerned with further shortening the duration of such flashes for application in light-flash stroboscopy to make possible higher flash repetition frequencies beneficial to both, clearer visual observation and sharper photographic recording of high speed phenomena.

The flash repetition frequency of spark-discharge stroboscopes employing a condenser discharge circuit with spark gap means is generally limited by the duration of each single flash. By proper selection of the constants of the discharge circuit and proper dimensioning of the spark gap means it has been achieved that the base of the energy conversion curve and thus the luminous flux intensity curve of the spark discharge over a time axis is no longer than about one microsecond, but even this interval is too long for many applications. In a typical curve of such discharge versus time relation as above referred to, it can be seen that the duration of substantial light emission is considerably shorter than one microsecond and only the approximately exponentially decaying extension or "tail" of the curve, caused by slow deionization and lasting for about 10 microseconds and being electrically detectable even after 1000 microseconds, prolongs the flash duration and thus limits the flash repetition rate in high frequency flash stroboscopy. This especially, since it has been found that for clear stroboscopic observation and sharp photographic recording of very high speed phenomena it is essential that there is a certain time interval between complete deionization of the spark gap after a spark discharge and the initiation of a subsequent one.

It is the principal object of this invention to provide means by which the "tail" of the luminous flux intensity curve of a spark discharge, which due to its low light emission contributes little to illumination, can be effectively cut off by forced interruption of the current flow through the spark gap at a predetermined instant to thus prevent secondary excitation of the gas ions in the gap.

It is another object of this invention to provide a luminous spark discharge device in which by forcedly shortening the duration of the spark discharge, the repetition rate of discharges can be immensely increased, for instance, to a range of 25,000 flashes per second.

The means as provided by this invention comprise a condenser discharge circuit in which quenched spark gap means are interposed in series with the light-emitting main spark gap whereby the quenched spark gap means are effective in controlling the initiation of sparkovers and in forcing cut-off or quenching of the discharge current prior to natural exponential decay.

In a modification of a discharge circuit according to this invention, an inductance coil is connected in parallel to the light-emitting spark gap for the purpose of converting into magnetic field energy of this coil a portion of the electrostatic energy discharged from the condenser

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in order to obtain a temporary voltage increase with the result that the current cut-off action of the quenched spark gap means becomes even more effective.

The quenching spark gap means, according to this invention, consist preferably of a pair of main electrodes and a plurality of individually insulated auxiliary electrodes forming a plurality of gaps whereby for faster cooling of these gaps the auxiliary electrodes have the form of discs and have considerable mass, and constitute a material of great heat absorption and heat storing capacity.

Furthermore, according to this invention, the quenched spark gap means are preferably sealed in a chamber containing a gaseous filling, such as hydrogen, which owing to its great molecular motion and high thermal conductivity is particularly suitable for carrying off considerable amounts of heat and reducing thereby thermooxidation in the gaps.

One or several of the auxiliary disc electrodes of the quenched spark gap means are, in accordance with this invention, in principle active electrodes in that they are connected to an external triggering power source for receiving controlled voltage pulses and thus become effective in initiating discharges at desired instants.

In some cases where a point light source is not essential it is possible to accommodate light spark gap and quenched spark gap in a common envelope containing the same gaseous atmosphere, whereby it is made possible that both spark gaps are utilized for illuminating the object under observation.

The advantages and features of this invention, as generally indicated above, and its entire scope will become more apparent from a study of the following detailed description of some embodiments thereof, which is to be read in connection with the drawings, in which

Fig. 1 is a graph displaying instantaneous values of energy conversion in the spark or its instantaneous luminous intensities, which latter are directly proportional to the former, of two subsequent spark discharges plotted over a time axis;

Fig. 2 is a schematic circuit diagram of a condenser spark discharge lamp according to one embodiment of the invention;

Fig. 3 is a modification of the same, including triggering means for initiating spark discharges;

Fig. 4 is a modification generally similar as the one shown in Fig. 3, but including an inductance coil parallel to the light spark gap;

Fig. 5 is a circuit diagram of an embodiment including several parallel-connected storage condensers and triggering means; and

Fig. 6 is a circuit diagram showing some modifications of the one shown in Fig. 5, wherein provisions are made for triggering both the quenched and the light spark gap.

The curves represented in Fig. 1 are typical energy conversion or luminous intensity versus time plottings of condenser spark discharges in a discharge circuit whose resistance has substantially the critical damping value. It will be noted that the total time taken by each discharge or flash is the actual discharge time plus the time interval between subsequent flashes. This total time $A+B+C$ necessary for each flash limits the maximum flash repetition frequency that is possible with conventional flashing equipment. As depicted in the figure, the curve has a very steep wave front, or a short rise-time, and a long substantially exponential decay spreading out in a long "tail" of the curve. On account of its small energy and luminous intensity amplitudes, the "tail" of duration B contributes very little to the energy conversion and thus to the light emission, but lasts for more

than 10 microseconds. In this respect it is detrimental to perfect stroboscopic illumination in that it renders blurred margins to the visible image and to photographic recordings. The slowly decaying extension of the curve is caused by a great number of gas ions that have been excited during the main discharge and whose excitation is maintained by a small current flow. Since the discharge time, according to the formula

$$t = \frac{2R \times W}{E^2}$$

(R =resistance in the discharge circuit, W =amount of energy charged in the condenser, and E =voltage at which the condenser is charged), is to a considerable extent governed by the voltage across the condenser at the beginning of the discharge, it could be reduced by an increase of this voltage. Such procedure, however, would involve an outlay too high for general application.

The present invention, aiming at overcoming the shortcomings pointed out above, provides for an interruption of the discharge current flow at will and thus does away with secondary excitation of the gas ions giving rise to afterglow, and this at a certain predetermined instant. To illustrate this feature with reference to Fig. 1, it is the aim of this invention to cut off the discharge current flow after a time interval corresponding to the distance A whose right-hand boundary still lies in the steep portion of the decaying curve so that during the time interval marked B the current flow is completely interrupted. In this way the interval C between flashes is increased by the time interval B . However, according to the invention, the decay period of duration B can be eliminated so that the duration of a flash period is reduced to $A+C$, and the flash frequency can be increased considerably. Interruption of the current flow according to this invention is effected by a quenched spark gap in principle similar to those well known in the art. But contrary to prior application of quenched spark gaps, which chiefly has been for the purpose of introducing a given amount of energy into an oscillatory circuit, it is here employed as a control gate or valve for the electrical energy in the discharge circuit. In accordance with this invention, the quenched spark gap performs two functions, first, it initiates the discharge and, second, it prematurely interrupts the current flow of the discharge.

The arrangement of a discharge circuit according to this invention is schematically shown in the circuit diagram Fig. 2. There the light-emitting spark gap means 1 is connected in series with the quenched spark gap means 2 to a storage condenser 3. Leads 4 and 5 are indicated for connecting condenser 3 to a suitable high-voltage direct-current power source for charging. The direct-current power source can be of any conventional type and can include transformer and rectifier to be fed from a common alternating current supply line. An adjustable or pre-set impedance or resistance 6 is preferably inserted in charging lead 4 to control the charging rate.

The light-emitting spark gap means, hereinafter generally referred to as light spark gap, can be a pair of properly spaced electrodes in open atmosphere, or it can be a spark gap in a sealed glass envelope filled with a type of gas and under a pressure beneficial to spark discharges in the form of sparkovers, or it can be the demountable spark discharge vessel as described and claimed in Letters Patent 2,703,374, titled Stroboscopic Light Source, issued March 1, 1955, to which reference may be made for further detail so that further description is considered unnecessary here.

The quenched spark gap means consists preferably of a pair of main electrodes 7, 8 and a plurality of individually insulated auxiliary electrodes 9 arranged in a row and forming a plurality of gaps 10. In order to minimize thermo-ionization in the gaps 10, an essential require-

ment for effective current cut-off, the temperature rise, caused by a desired series of discharge flashes, must be kept low. To this end, the electrodes 7, 8 and 9 are in the form of discs having considerable mass and constitute a material having great heat absorbing and storing capacity, such as, for instance, aluminum. Moreover, to further expedite cooling, the quenching spark gap means is preferably arranged in a sealed enclosure 11 containing a gaseous filling preferably of hydrogen. Hydrogen, owing to its inter-molecular motion and thereby effected high thermal conductivity and heat transfer, is particularly suitable and beneficial in preventing as much as possible thermo-ionization in the gaps.

With the simple system as shown in Fig. 2 series of flashes at extremely high repetition frequencies can be produced whereby the repetition frequency depends (1) on the voltage by which the condenser is charged, (2) on the charging rate controlled by impedance or resistance 6, and (3) on the constants of the discharge circuit and the number and length of the auxiliary gaps in the quenched spark gap means. Flashing frequencies of 1000 per second and up to the order of 25,000 per second have thus been obtained, and this at fairly accurate recurrence, in fact, accurate enough for most perfect high speed photographic recording.

For controlled flashing, i.e., for triggered initiation of the flashes by external means an embodiment of the invention as shown in Fig. 3 can be employed. Here some of all of the auxiliary electrodes 9 are connected to an external triggering device for the purpose of imparting voltage pulses thereto and thus initiating and timing the discharges. In the form of triggering device depicted in Fig. 3 each of the triggered electrodes is associated with one individual secondary 14a, 14b, 14c of an impulse transformer 12 whose primary 13 is provided with leads 27 and 28 to be connected to a voltage pulse source for receiving voltage pulses of the desired flashing frequency. Such voltage pulses when imparted to one or several of electrodes 9 will ionize the gas in the appertaining gaps 10 and thus initiate the main discharge of condenser 3 through the light spark gap 1 and all gaps 10 in a manner generally known in the art. The condensers 15, inserted in the connections to electrodes 9 are of very low capacitance and prevent diversion of the main discharge or a portion thereof into the triggering circuit. High ohmic resistors 16 are shown connected across condensers 15 and secondaries 14a, 14b, 14c to provide leak connections for condensers 15. These resistors, however, are optional and not absolutely necessary for functioning of the system.

The light spark gap means and quenched spark gap means may be accommodated in a common enclosure if desirable and such a construction is indicated in Fig. 3. The gaseous filling of the enclosure in this case is preferably argon at a pressure in the range from 1 to 5 atmospheres because such gas and pressure are beneficial to the light quality of spark discharges. Cooling, on the other hand, is not so effective as with hydrogen, but is sufficient as long as operation is intermittent and for short periods only. Mounting and anchoring of the auxiliary electrodes 9 in place can be by any known means and ceramic spacers 10a are indicated to serve that purpose in Fig. 3. They are not shown in the other figures for reason of clearness. A construction using a common enclosure of transparent material, such as glass or quartz, gives some advantages in that also the light inherent in quenching sparks can be utilized for illumination to a certain extent if a point light source is not essential.

It has been found advantageous to connect in parallel to the light spark gap an inductance coil 17, as shown in Fig. 4, which during condenser discharge absorbs a portion of the discharge energy released in the quenching spark gap means by converting dielectric energy of the condenser into magnetic energy of the inductance coil in

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accordance with the well-known equation $\frac{1}{2}CE^2 = \frac{1}{2}LI^2$ (C =capacitance of the condenser, E =voltage by which the condenser is charged, L =inductance of the coil, and I =current). Such energy storing in the inductance coil connected in parallel to the light spark gap results in a voltage increase across this gap, thereby assisting the action of the quenched spark gap means 2 in reducing the duration of the light-producing discharge.

In a modified arrangement of circuit elements as shown in Fig. 5, a plurality of storage condensers 3a, 3b, 3c, 3d is connected in parallel to the charging and discharging connections, whereby switches 18b, 18c, 18d are interposed in the respective condenser connections with exception of condenser 3a which has no switch and remains permanently in circuit. Condenser 3a represents the lowest value of capacitance with which the system can be operated. By closing one, two or all three of the switches 18b, 18c and 18d before a series or train of flashes is triggered, the effective capacitance in the circuit can be selected to give best results at a desired repetition frequency. Selective capacitance is desirable particularly in order to gain an optimum of brightness on the one hand and to avoid overheating on the other hand. It will be clear that to prevent overheating the energy converted in the spark gaps within a certain unit of time must not surpass a predetermined maximum value. Thus the condenser charging rate and the effective capacitance must be reduced for higher flashing frequencies and longer uninterrupted flashing periods.

In the system shown in Fig. 5, one side of the circuit is grounded and also one lead 27 of the primary 13 of the impulse transformer 12, receiving the triggering pulse for the quenched spark gap means 2, is connected to ground. For operation, the high-voltage direct-current power source is connected to leads 4 and 5, and the source of voltage pulses for triggering controlled flashes, to leads 28 and 5. It may be mentioned here that for illuminating an object under observation, the light spark gap can, of course, be arranged in a suitable reflector, preferably at the focal point of such, and a reflector is indicated in dotted lines at 26 in Figs. 5 and 6.

The circuit shown in Fig. 6 incorporates a light spark gap 1 which itself is provided with a trigger, or ignition, electrode 19 and which thus also in this respect is identical to the demountable spark gap means described in the aforementioned Patent 2,703,374; in fact, the there described stroboscopic light source may be employed in the circuit shown. Concerning the required connections it will be noted that the primary 13 of impulse transformer 12 for the quenched spark gap means and the primary 21 of the impulse transformer 20 for the light spark gap are connected in series when the pulse is fed into lead 28. It will also be noted that an additional lead 23 is joined to the connection 24 between primaries 13 and 21 so that when a pulse is fed into lead 23 only the light spark gap 1 is triggered, because primary 13 is then not in circuit. Furthermore, a three-position switch 25 is provided which in position *a* switches inductance coil 17 to lie parallel to the light spark gap, in position *b* disconnects the inductance coil, and in position *c* short circuits and thus eliminates the quenched spark gap means 2 from the discharge circuit. The arrangement of a plurality of storage condensers 3a, 3b, 3c, 3d and of switching means 18b, 18c, 18d, as well as charging leads 4, 5 and impedance or resistance 6 is similar to that shown in Fig. 5. Here also one side of the circuit is grounded.

Several modes of operation are possible with the system disclosed in Fig. 6. For all such modes of operation the condenser charging source is connected to leads 4 and 5, whereby, however, the charging rate and the effective capacitance must be adjusted by means of impedance 6 or switches 18b, 18c, 18d to values suitable for the desirable performance. Connecting the triggering pulse source to leads 28 and 5, and setting switch 25 in position *a* results in discharge flashes triggered by pre-

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ionization of gaps in the quenched spark gap means 2 and also of the light spark gap with inductance coil 17 in parallel to the latter. Such multiple triggering is beneficial to most accurate timing for flash repetition frequencies above 1000 per second. By setting switch 25 in position *b*, the inductance coil can be disconnected at will. When feeding triggering pulses by way of lead 23 with switch 25 in position *c*, it will be noted that the quenched spark gap means 2 is shorted out of circuit and receives no triggering pulses so that it becomes inoperative and only the triggered light spark gap is utilized. This mode of operation is entirely satisfactory for flashing frequencies in the lower range, for instance, up to 1000 flashes per second, and obviates the losses which otherwise unavoidably occur in the quenched spark gap means. Still another mode of operation is possible which gives an accuracy of flash recurrence, particularly at highest frequencies, that is precise enough for sharp high-speed photographic recordings. In this mode of operation, no triggering pulses are fed either to the quenched spark gap or to the light spark gap, but the quenched spark gap 2 and the inductance coil 17 are put in circuit by setting switch 25 in position *a*. Then, upon connecting leads 4 and 5 to the power source and adjusting the charging rate by variable resistance 6 and the constants of the discharge circuit, such as effective capacitance, pressure in the gap enclosures and electrode spacing, to suitable values, trains of flashes can be produced at the relaxation rate of the circuit. This manner of operation has already been described with reference to Fig. 2, but the circuit of Fig. 6 is more versatile in that it allows for various changes of the circuit constants.

After this discussion it will be appreciated that by applying the several modes of operation made possible by an arrangement of circuit elements disclosed in Fig. 6, most reliable and efficient operation in any specific working range of frequencies can be obtained.

Moreover, from the foregoing description it will be clear that by the means provided by the present invention it is made possible to increase the optically useable flash repetition frequency of light-flash stroboscopes to 25 kilocycles per second and more, and this by extremely reducing the duration of each flash without considerable loss in its brightness.

It will be understood that not only light-flash stroboscopy will benefit from the disclosures of this invention, but that they will be very useful also in other fields wherever flashes, single or in random succession, of extremely short duration are of primary importance. When speaking of flashes of extremely short duration in this specification it is to be understood that flashes lasting not longer than one microsecond are meant.

What is claimed is:

1. A light source for emitting light flashes produced by electric spark discharges of extremely short duration, comprising a storage condenser, means for charging said condenser from a high-voltage direct-current source, a discharge circuit for said condenser including an electric light spark gap means and a quenching spark gap means in series arrangement, said quenching spark gap means having a discharge time characteristic shorter than that of said light spark gap means for being effective in interrupting discharges across said light spark gap means prematurely prior to their natural exponential decay, and means associated with said quenching spark gap means for triggering controlled condenser discharges through said discharge circuit.

2. The light source as claimed in claim 1, wherein an inductance coil is shunted across said light spark gap means for converting into magnetic field energy a portion of the electrostatic energy discharged from said condenser and thereby temporarily increasing the voltage across said light spark gap during discharge and assisting the discharge-interrupting action of said quenching spark gap means.

3. In a lamp of the character described, light spark gap means and quenching spark gap means in series arrangement, said spark gap means comprising a plurality of individually insulated auxiliary electrodes arranged in spaced relation to one another in a row and forming a plurality of quenched spark gaps, a main electrode at each end of said row having means for connecting respectively to the terminals of an electric energy discharge source, the gap between one of said main electrodes and the subsequent auxiliary electrode in the row forming a light spark gap, all other gaps forming quenched spark gaps, means for connecting at least one of said auxiliary electrodes to a pulse source of electric energy for, when said spark gap means are operative, triggering discharges through said row of spark gaps, and a transparent enclosure common to all spark gaps including a gaseous filling, whereby also said quenched spark gap means can be utilized for illumination.

4. An electric system for a lamp producing sparklight flashes of extremely short duration comprising, in combination, a plurality of storage condensers, means for connecting said condensers in parallel to a high-potential direct-current power source, a variable impedance interposed in said connecting means for limiting and adjusting the charging rate of said condenser, switching means associated with at least one of said condensers for changing the effective capacitance in circuit, a discharge circuit for said plurality of parallel-connected storage condensers including light spark gap means and quenched spark gap means in series connection, an inductance coil shunted across said light spark gap means, and means associated with said quenched spark gap means for imparting pulses of electric energy thereto to initiate discharges from effectively connected storage condensers through said discharge circuit to cause light flashes by sparkovers in said light spark gap means, whereby said quenched spark gap means also traversed by the discharges is effective in interrupting the discharges prior to their natural exponential decay.

5. An electric system for a lamp producing sparklight flashes of extremely short duration by spark discharges comprising, in combination, a plurality of storage condensers, means for connecting said condensers in parallel to a high-potential direct-current power source for charging said condensers, a variable impedance interposed in said connecting means for controlling the charging rate of said condensers, switching means associated with at least one of said condensers for changing the effective capacitance in circuit, a discharge circuit for said plurality of parallel-connected storage condensers including light spark gap means and quenched spark gap means in series connection, an inductance coil, three-way switching means operative in one position to shunt said inductance coil across said light spark gap means, in the other position to disconnect said inductance coil from circuit, and in the third position to short-circuit said quenched spark gap means, and means associated with said light spark gap means and said quenched spark gap means for imparting pulses of electric energy to at least one of said spark gap means to initiate discharges from effectively connected storage condensers through said discharge circuit to cause light flashes by sparkovers in said light spark gap means, whereby said quenched spark gap means also traversed by the discharges is effective in interrupting the discharges prior to their natural exponential decay.

6. The electric system as defined in claim 5, wherein said means for imparting pulses of electric energy to at least one of said spark gap means includes an impulse transformer having its secondary connected to said light spark gap means, and a second impulse transformer having a plurality of secondaries each one connected to said quenched spark gap means, each transformer having a primary, a pulse circuit through both primaries in series connection to impart pulses to both spark gap means, and a pulse circuit through the primary of said

first-named transformer only to impart pulses to the light spark gap means only.

7. A spark lamp for emitting light flashes of extremely short duration, comprising, in combination, capacitive storage means of predetermined capacity; circuit means connecting said storage means with a source of direct-current energy for charging said storage means and including means for predetermining the charging rate of said storage means; and a discharge circuit connected to said storage means and including a series-combination of plain spark gap means for emitting a light flash upon application of a predetermined breakdown potential, and of quenched spark gap means having a predetermined breakdown potential so selected that the sum of said breakdown potentials determines the start of a spark discharge across said plain spark gap means when said storage means is charged to a potential substantially equal to said sum, the discharge time characteristic of said quenched spark gap means being shorter than that of said plain spark gap means to such an extent that flow of energy across said plain spark gap means and light emission therefrom is terminated at the end of the discharge time period of said quenched spark gap means, whereby start and end of the duration of flash light emission at every spark discharge are controlled by said quenched spark gap means.

8. A spark lamp for emitting light flashes of extremely short duration, comprising, in combination, capacitive storage means of predetermined capacity; circuit means connecting said storage means with a source of direct-current energy for charging said storage means to a predetermined charge potential and including means for predetermining the charging rate of said storage means; a discharge circuit connected to said storage means and including a series-combination of plain spark gap means for emitting a light flash upon application of a predetermined breakdown potential, and of quenched spark gap means having a predetermined typical breakdown potential, so selected that the sum of said breakdown potentials is higher than said predetermined charge potential of said storage means, said quenched spark gap means comprising a series of electrode plates spaced from each other by spark gaps of very small size as compared with the face areas of said plates; and trigger pulse supply means connected with at least one of said plates located intermediate between the first and last plates, respectively, of said series of plates for applying timed triggering pulses to said one plate for reducing momentarily said typical breakdown potential of said quenched spark gap means to such an extent that discharge of said storage means across said series-combination of spark gap means is initiated, the discharge time characteristic of said quenched spark gap means being shorter than that of said plain spark gap means to such an extent that flow of energy across said plain spark gap means and light emission therefrom is terminated at the end of the discharge time period of said quenched spark gap means, whereby the start of flash light emission is controlled by the application of said trigger pulses and the end of the duration of flash light emission at every spark discharge is controlled by said quenched spark gap means.

9. The light source as claimed in claim 8, wherein an inductance coil is shunted across said plain spark gap means for converting into magnetic field energy a portion of the electrostatic energy discharged from said storage means and thereby temporarily increasing the voltage across said plain spark gap during discharge and assisting the discharge-interrupting action of said quenched spark gap means.

10. A lamp as claimed in claim 8, wherein said quenched spark gap means includes means for surrounding said electrode plates with an atmosphere of gas having lower atomic weight than the atmosphere surrounding the electrodes of said plain spark gap means.

11. A lamp as claimed in claim 8, wherein said

quenched spark gap means includes enclosure means surrounding said electrode plates and filled with an atmosphere of hydrogen.

12. A lamp as claimed in claim 8, wherein said plate electrodes are made of material and are dimensioned for being capable of absorbing and dissipating substantially all the heat generated by spark discharges between said plates so as to reduce the spark-quenching time to a minimum.

13. A spark lamp for emitting light flashes of extremely short duration, comprising, in combination, capacitive storage means of predetermined capacity; circuit means connecting said storage means with a source of direct-current energy for charging said storage means and including means for predetermining the charging rate of said storage means; and a discharge circuit connected to said storage means and including a series-combination of plain spark gap means for emitting a light flash upon application of a predetermined breakdown potential, and of quenched sparkgap means so selected that the sum of the breakdown potentials of said plain and quenched

spark gap means determines the start of a spark discharge across said plain spark gap means when said storage means is charged to a potential substantially equal to said sum, the discharge time characteristic of said quenched spark gap means being shorter than that of said plain spark gap means to such an extent that flow of energy across said plain spark gap means and light emission therefrom is terminated at the end of the discharge time period of said quenched spark gap means.

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