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Ludloff

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[54] **FLASH LIGHTING ARRANGEMENT**

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[51] **Int. Cl.**.. **H05h 37/00**

[58] **Field of Search**....... 313/185; 315/241 P, 241 S

[56] **References Cited**

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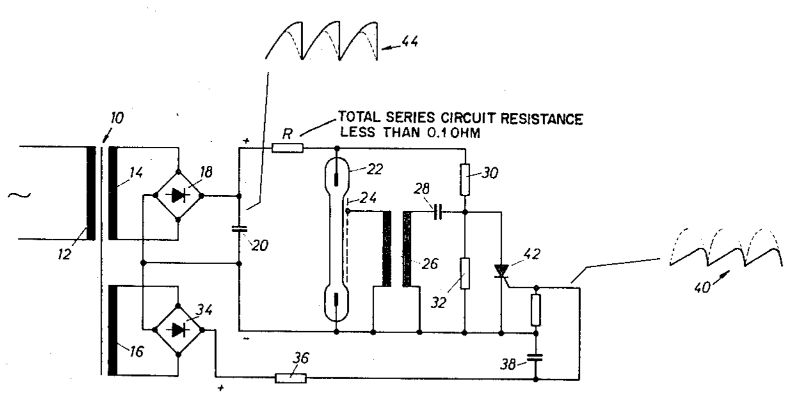
[57] **ABSTRACT**

For generating short-wave radiation flashes an electron flash tube is operated with such a small resistance in the discharge circuit that the peak current of the discharge is substantially defined only by the flash tube the resistance of the remaining discharge circuit being negligible. The tube contains a dead space and is preferably operated stroboscopically at a frequency in the order of magnitude of the main frequency.

4 Claims, 9 Drawing Figures



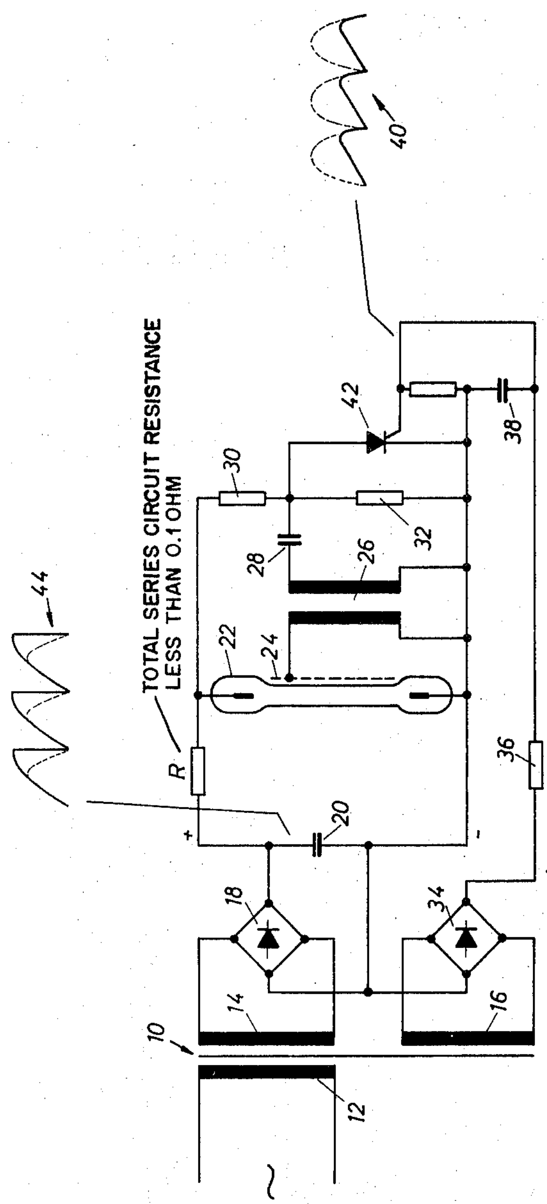
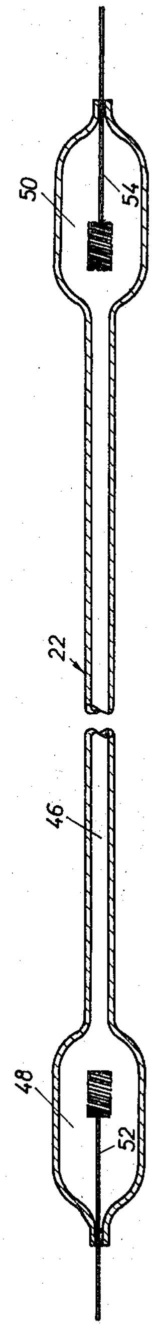

TOTAL SERIES CIRCUIT RESISTANCE
LESS THAN 0.1 OHM
R
44
40
42
30
32
28
26
24
22
20
18
34
36
38
10
12
14
16

Fig.1


50
54
22
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48
52

Fig.2

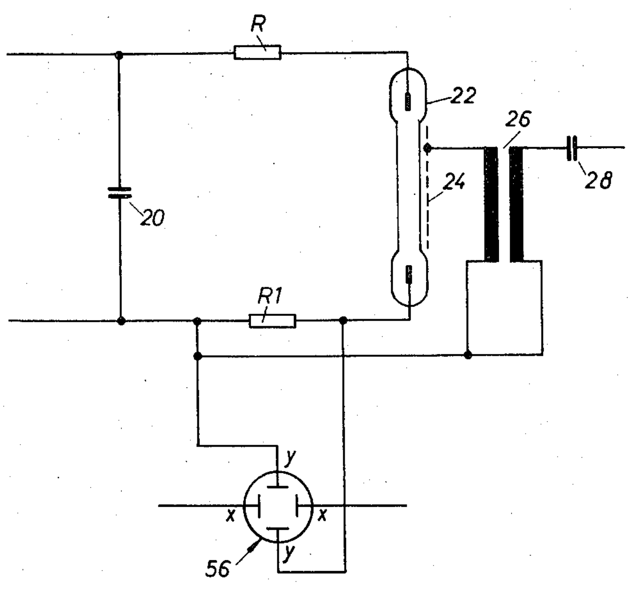

Fig. 3

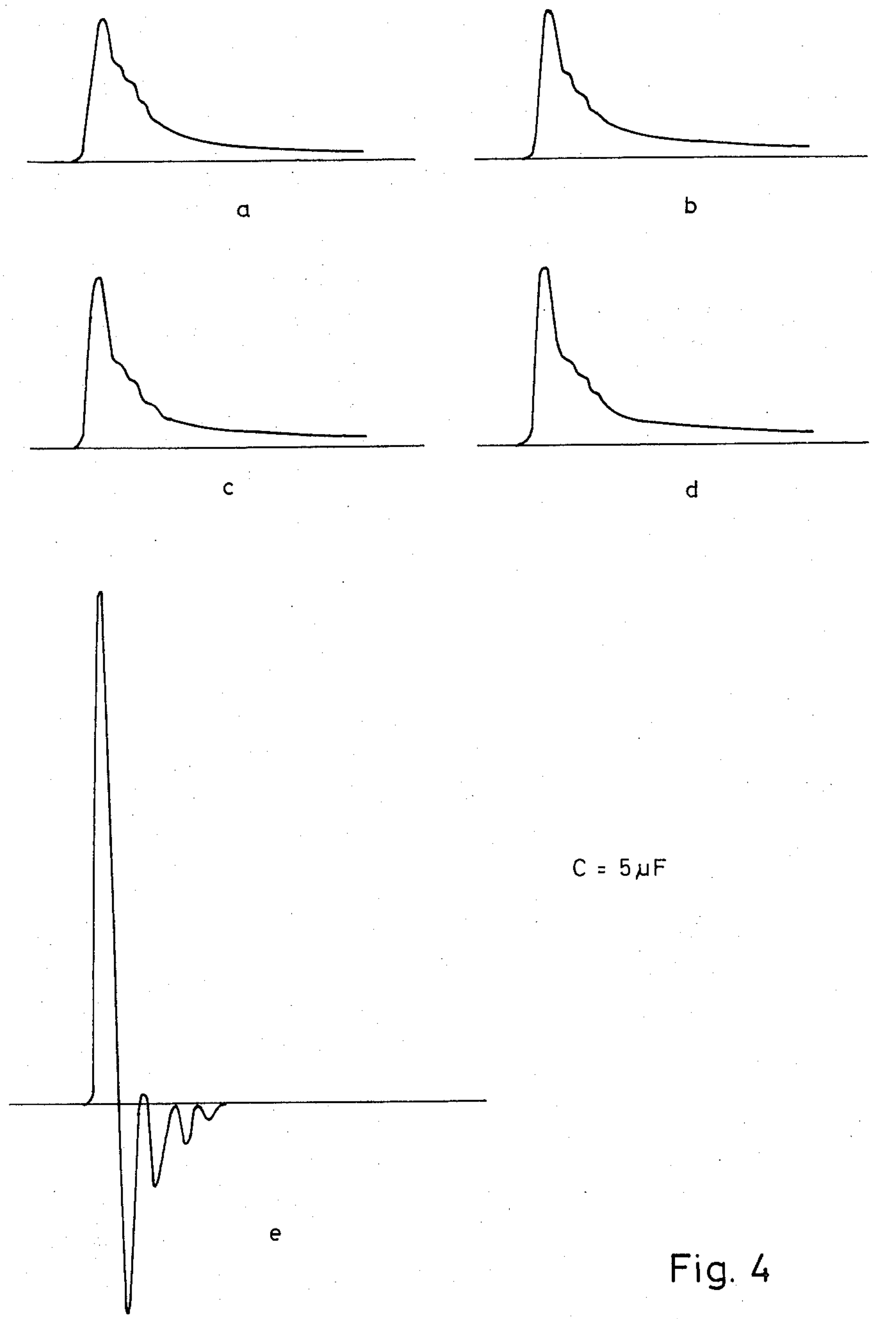

Fig. 4

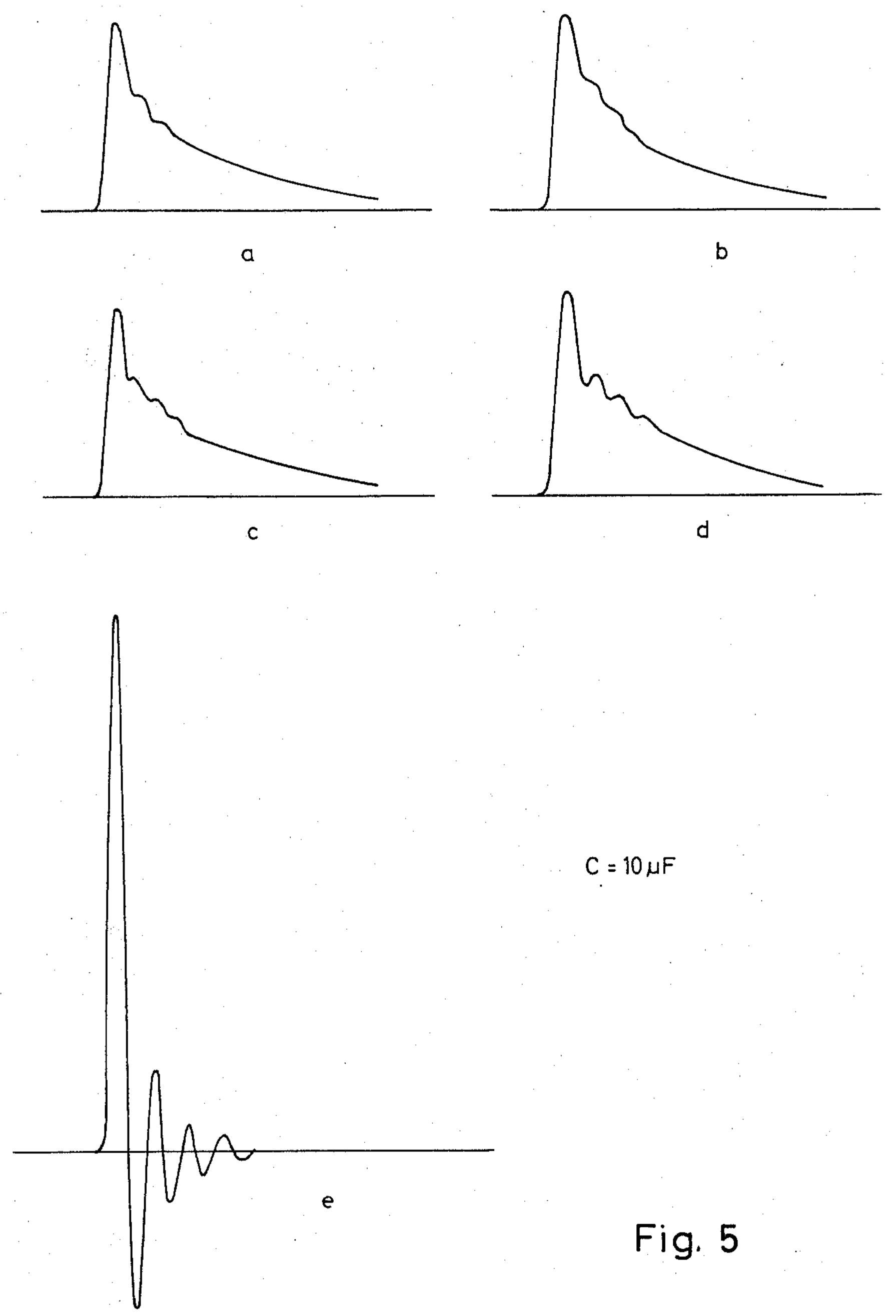

Fig. 5

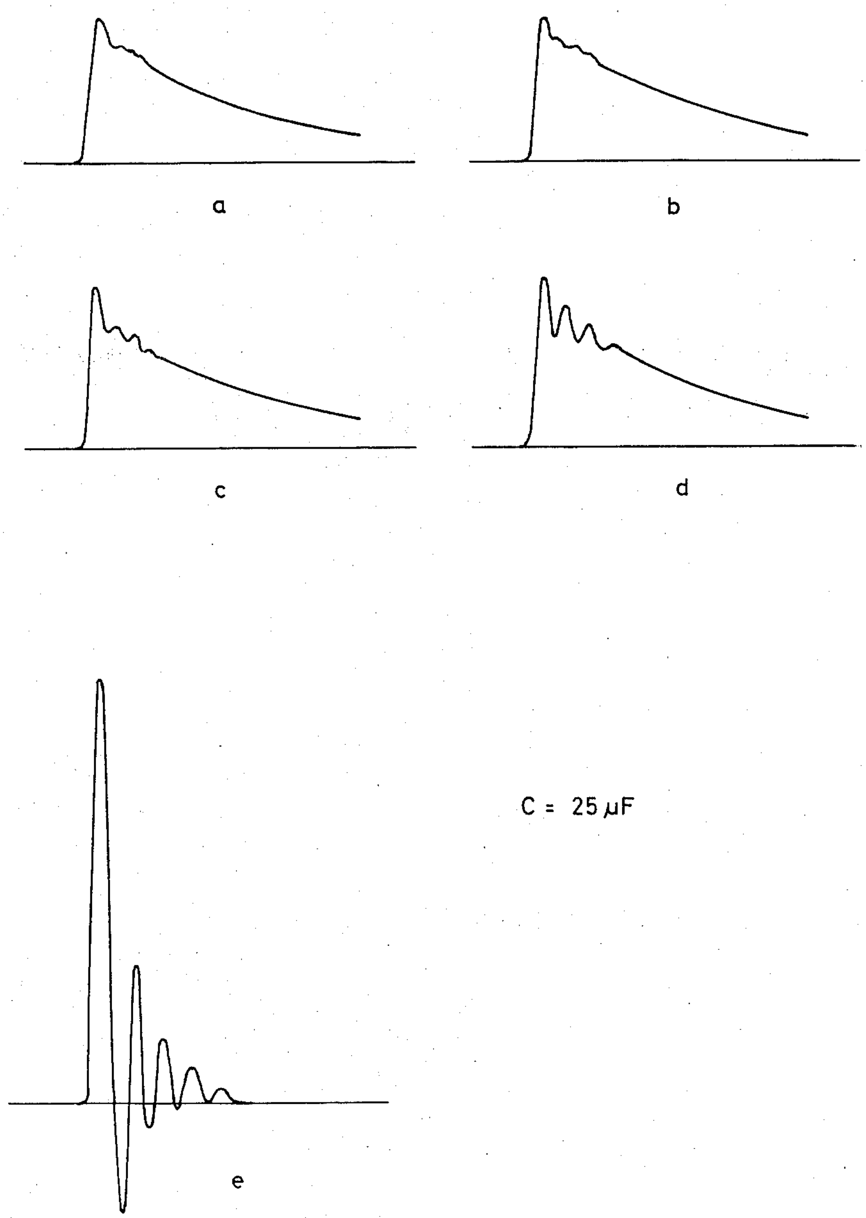

Fig. 6

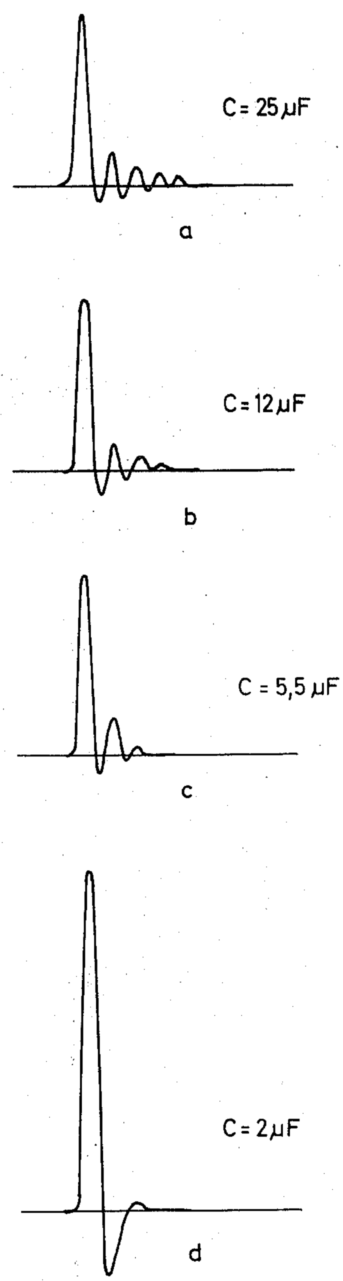

Fig. 7

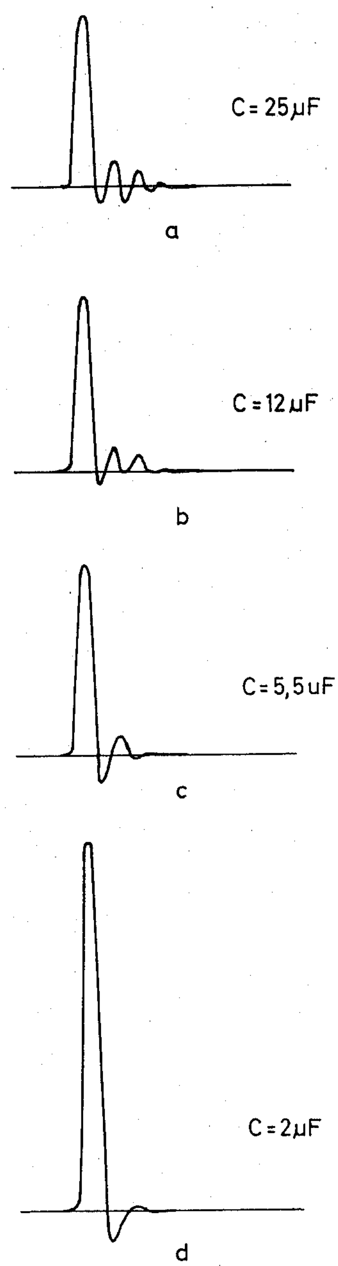

Fig. 8

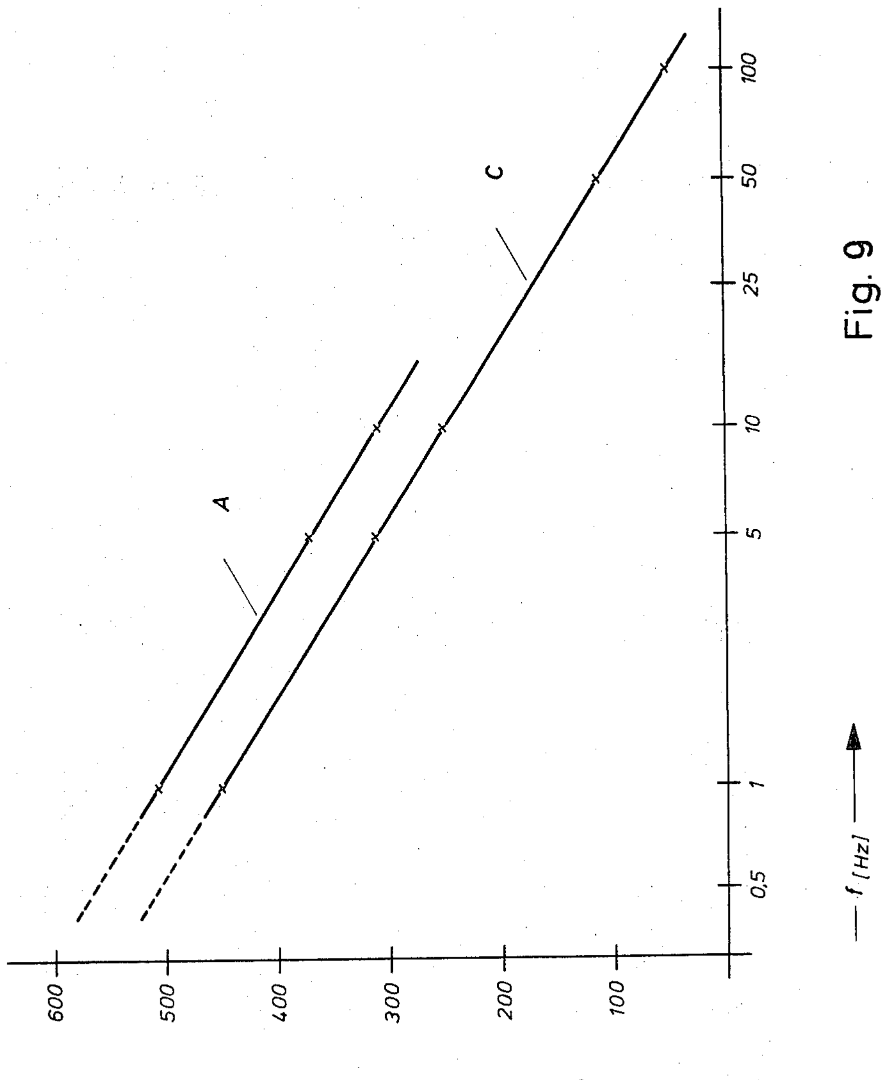

Fig. 9

FLASH LIGHTING ARRANGEMENT

This invention relates to a flash lighting arrangement for generating short-wave radiation flashes of high intensity by using an electron flash tube ignitable by means of ignition electrode and a storage capacitor discharging via the electron flash tube.

Arrangements of the type indicated are used in connection with the photoinitiation of drying or hardening processes, for instance, in varnishes or printing inks, in which an influence as temporary, but intensive as possible of short-wave radiation is of importance, while avoiding inadmissible heating by long-wave radiation. Tests of this type have been carried out and have also led to positive results, however, these positive results were not reliably reproducible. Tests which had a positive result once with specific flash tubes, storage capacities and charging voltages and showed good drying or hardening effects, at other times could not be reproduced under apparently the same conditions.

The invention is based on an examination for such flash lighting arrangements for the photoinitiation of drying or hardening processes with the goal of determining the parameters critical for a positive result of the respective tests and of indicating teachings for technical action which lead to reliably reproducible results.

According to this invention provision is made that the electron flash tube is operated with such a small resistance in the discharge circuit that the peak current of the discharge is substantially determined by the flash tube only.

This condition can be checked in that then, for instance a further reduction of the resistance in the dicharge circuit has no noticeable influence on the flash current.

It has been shown that immediately after ignition in the initial stage of the flash discharge the resistance of the flash tube is extremely small which apparently is due to the fact that the gas in the flash tube has not yet been heated by the discharge. The flash tube resistance first is of an order of magnitude of milliohm and thus, is smaller by orders of magnitude than the values of a few ohms which are generally indicated as flash tube resistance during normal discharge. In this initial stage of the flash discharge, therefore, the ohmic resistance of the leads, also if small with respect to the indicated "normal" flash tube resistance and amounting, for instance, to 0.1 ohm, has a noticeable influence. A reduction in the lead resistances to bring the discharge circuit resistance to critically low value, suddently resulted in a considerable increase in the peak currents of the flash discharge. It has been shown in this connection that a useful photochemical effect is reliably obtained. The critically low value, in addition to being below 0.1 ohm, may be further defined as a value at which the discharge current value is determined substantially by the tube itself, and the flash current has the characteristics of an oscillation, i.e., the characteristics of a substantially undamped condenser discharge, in that its heavy surge steeply dissipates and is of substantially shorter duration than, for example, the current flow of a sine wave producing the same frequency of flashes.

With a sufficient reduction in the lead resistances an oscillation of the flash current occurred, passing through the zero point and at the same time caused a strong increase in the peak current in the first oscillation half-wave at small half width. This oscillation does not consist in a discharge and a change in charge of the storage capacitor, as it would occur in a normal oscillatory circuit. The capacitor is rather discharged substantially exponentially. Now, it has furthermore been shown that these flash discharges of high intensity and connected with oscillations show particularly good photochemical effects.

Moreover, it is particularly advantageous if there is provided a flash tube of UV-transmitting material including a discharge channel and which includes a dead space disposed outside of the discharge channel, whose volume is at least equal to the volume of the discharge channel.

It has been found that with such a flash tube under otherwise same conditions a drying of printing ink in less than a tenth of the time is attainable than with a flash tube without such dead space.

Moreover, it has been shown during tests, on the one hand, with same flash frequency and different capacity of the storage capacitor, and on the other hand, with same capacity and different flash frequency that though an increase in the capacity leads to a proportional shortening of the drying time, however, an increase in the flash frequency has a substantially stronger effect, approximately exponentially in the meaning of a shortening of the drying time. As the capacity of pulsating flash tube is given by the product of frequency f and energy $W = C/2\ U^2$, and as the tube has a given power rating, it is advantageous to operate with relatively small energy per flash, thus small capacity of the storage capacitor, and a higher flash frequency instead. In a further modification of this invention provision is therefore made that the flash tube is operated stroboscopically at a frequency of half of, to double the mains frequency, such as between 25 to 100 cycles, the energy of each individual flash being dimensioned in accordance with the rating of the tube.

A few illustrative embodiments of this invention will now be described more fully with reference to the accompanying drawings, in which:

FIG. **1** illustrates a circuit diagram of an instrument according to the invention.

FIG. **2** illustrates a flash tube preferably used with the invention.

FIG. **3** illustrates the measuring arrangement used in the examinations on which the invention is based.

FIGS. **4***a* – *e* illustrate flash current curves which were observed in a first type of tube with different resistances in the discharge circuit at a capacity of the storage capacitor of 5 μF with the measuring arrangement of FIG. **3.**

FIGS. **5***a* – *e* and FIGS. **6***a* – *e* illustrate respective curves for a capacity of the storage capacitor of 10 μF, respectively 25 μF. FIG. **7***a* – *d* illustrates the flash current waveforms for another type of flash tube at different capacities of the storage capacitor.

FIG. **8***a* – *d* shows respective illustrations for a flash tube of the same type as in FIG. **7,** but with lower gas pressure.

FIG. **9** illustrates the dependence of the photochemical effect on the flash frequency.

INSTRUMENT SETUP

A transformer **10** (FIG. **1**) to whose primary winding **12** the a.c. voltage from mains is applied, has two secondary windings **14** and **16.** A rectifier bridge **18** via which a storage capacitor **20** is charged, is connected to the secondary winding **14.** The storage capacitor **20** is connected to an electron flash tube **22,** the ohmic resistance of the outer discharge circuit (capacitor, lead-ins without flash tube) being symbolized by the resistance R.

The flash tube **22** is ignited via an ignition electrode **24,** which is connected in the customary manner to the secondary side of an ignition transformer **26.** Via the primary winding of the ignition transformer **26** an ignition capacitor **28** discharges and generates an ignition pulse across the ignition electrode **24,** by which the flash tube **22** is ignited. The ignition capacitor **28** is charged by the d.c. voltage applied to the flash tube **22** via a respective voltage divider **30, 32.** The discharge takes place periodically at double the mains frequency, for instance, 100 cycles, and the flash tube **22** is ignited at the same frequency.

For this purpose, the secondary winding **16** of the transformer **10** is effective to charge a capacitor **38** via a rectifier bridge **34** and a charging resistor **36,** whose voltage in case of appropriate dimensioning rises approximately according to the curve **40** (FIG. **1**) and finally ignites a thyristor **42** which discharges the ignition capacitor **28** via the primary winding of the ignition transformer **26.** AT the same time, also the capacitor **38** discharges via the ignition path of the thyristor. This takes place during each halfperiod of the a.c. voltage from mains, so that during each halfperiod the storage capacitor **20** is charged approximately according to the curve **44,** the flash tube **22** is ignited and the storage capacitor discharges via the same.

The electron flash tube **22** is shown in a longitudinal section in FIG. **2.** It has a relatively narrow straight tubular discharge channel **46.** This discharge channel is followed by dead spaces **48, 50** on both sides, the volumes of each of the dead spaces being approximately equal to the volume of the discharge channel **46.** The electrodes **52, 54** extend axially through the spaces **48, 50** and end just short of the ends of the discharge channel so that there is almost no discharge in the spaces **48, 50.** The cross-section of the discharge channel **46** is not completely filled out by the flash discharge. The electron flash tube consists of UV-transmitting quartz.

The described preferred embodiment with respect to the critical data was designed as follows:

Capacity of the storage capacitor 20 : 20 μF (low-ohmic metallic paper capacitor)

Charging voltage of the storage capacitor: 3200 volts

Lead resistance R<5 milliohms

Tube data:

Discharge length 450 mm, internal diameter of the discharge channel 4 mm, filling pressure 350 mm mercury column, filling gas: xenon.

MEASURING ARRANGEMENT

FIG. **3** illustrates schematically a measuring arrangement with which the effects of the different parameters on the course and the photochemical effect of the generated flash discharge were investigated. Corresponding parts are referenced by the same reference numerals as in FIG. **1.**

An ohmic measuring resistor R_1 is connected in the discharge circuit. The voltage dropping across this measuring resistor was applied to the y-plates of a storage oscillograph. The resistor R_1 was varied in part of the tests.

MEASUREMENTS

Three different types of flash tubes were operated with:

Type A is a customary flash tube of 4 mm internal diameter and a dead gas volume as small as possible.

Type B is a flash tube of 10 mm internal diameter and electrodes directly melted into the ends similarly to type A.

Type C is a flash tube similar to FIG. **2** with dead spaces at each end of the discharge channel which latter also has an internal diameter of 4 mm.

In one embodiment a straight flash tube of type A of 400 mm length and an internal diameter of 4 mm and filled with inert gas was operated with, whose gas pressure was 270 mm mercury column. The storage capacitor was a metallic paper capacitor. For different storage capacitors of 5 μF, 10 μF and 25 μF with different lead resistances R, respectively, measuring resistors R_1, the discharge curves were obtained which can be seen from the FIGS. **4***a* to *e* to **6***a* to *e*.

It can be seen that the amplitude of the flash current with a decrease in the lead resistances first increases to a relatively small extent only, for instance from 550 amps to 595 amps, while maintaining the normal exponential discharge course. At a specific small lead resistance, however, a damped oscillation passing through zero is formed, the amplitide of the oscillation rising very strongly, for instance to 3640 amps at 5 μF. It can be seen that such oscillations are superimposed on the exponential discharge curve weakly previously already and increasingly with decreasing lead resistance.

It can further be seen from FIGS. **4** to **6** that at 5 μF the dying-out oscillation line lies completely in the negative, at 25 μF completely in the positive. For a storage capacity of 10 μF an oscillation form is obtained which is substantially symmetrical towards the zero line. Still further it can be seen that this oscillation course of FIG. **5** also under otherwise same conditions leads to a maximum current peak of 4,730 amps.

Besides, the peak current is substantially proportional to the voltage to which the storage capacitor is charged. Accordingly, the photochemical effect of the flash discharge changes, at which apparently primarily UV-radiation is produced.

Therefore, the teaching of this examination for flash tubes of the type A is in summary:

a. For a given flash tube the lead resistance is reduced until an oscillation passing through zero is produced in the flash tube.

b. At such a state a variation of the storage capacity can be effected until the oscillations extend symmetrically to the zero line.

This state is reproducibly connected with high peak currents in the initial stage of the discharge, which show a good photochemical effect provided the current strength exceeds a certain value. In the described examinations a peak current — measured in the described measuring arrangement under the assumption of a strictly ohmic resistance R_1 — of about 2,000 amps was found to be necessary in order to obtain useful results.

With a flash tube of type B similar conditions as with the flash tubes of type A were obtained, however, the optimum of the obtained oscillation effect being found at greater capacities of the storage capacitor, approx. 25 – 30 μF. However, the photochemical effect deteriorated as compared with flash tubes of the type A under same conditions.

With flash tubes of the type C no marked optimum of the oscillation effect in dependence on the capacity of the storage capacitor **20** was obtained. This can be seen from the curves in FIGS. *7a – d* and FIGS. *8a – d* taken with such flash tubes. The capacity, and therewith the energy stored in the storage capacitor **20** only influences the number of oscillations which occur until the capacitor is discharged.

As is recognizable from a comparision of the FIGS. **7** and **8**, with tubes of the type C — in contrast to the types A and B — within broad limits practically no dependence on the filling pressure of the tube is obtained. FIG. **7** was recorded on a flash tube with a filling pressure of 350 mm mercury column, FIG. **8** on a flash tube with a filling pressure of 250 mm mercury column. With flash tubes of the type A or B oscillation effects of the described type are only obtained at relatively low filling pressures < 280 mm mercury column.

The photochemical effect of the radiation flashes so generated was investigated by means of printing ink samples, wherein as a measure for the effectiveness of the radiation flashes determination was made of the number of flashes was needed for sufficient drying of the printing inks (no smearing). Check examinations were made in that a part of each sample was covered as reference by an aluminum sheet. The following results were obtained:

For all flash tubes the best drying effects, respectively drying effects occurred at all only when the flash tube was operated in a condition in which the described oscillations were observed distinctly, type A being somewhat better than type B. With flash tubes of the type C, however, drying effects better by a factor of about 10 than with the other tubes were obtained.

With flash tubes of the type C an approximately linear connection between the capacity of the storage capacitor and therewith the flash energy (Wsec) and the drying effect was observed.

Moreover, the dependence of the drying effect, namely of the number of flashes required for drying at a given energy of each individual flash was examined. In this connection the decreasing logarithmic dependence of FIG. **9** was obtained. Accordingly thereto, it is favourable to operate at higher frequencies in order to attain drying times as short as possible.

SUMMARY

Thus, it has been found to be favourable to use a flash tube of the type C. The lead resistance should be maintained as small as possible so that it practically has no influence on the discharge. In this manner, a state of oscillation of the flash current is maintained causing high initial current peaks. Such initial current peaks have a good photochemical effect. For a given (thermal) loading capacity of the flash tube a relatively small capacity of the storage capacitor (flash energy per flash) should be selected, while providing a higher flash frequency. The described preferred embodiment of FIGS. **1** and **2** is typical thereof.

The described phenomena could possibly be interpreted in the following manner:

The emission of short-wave UV is essential to the photochemical effect (varnish drying, drying of printing inks). This also results from theoretical considerations and is known per se. Such ultraviolet radiation occurs primarily at low gas pressure of a flash tube. If by the flash discharge in the course thereof the gas pressure increases, the emitted spectrum moves towards the visible and longwave. The provision of dead spaces in the gas chamber of the flash tube according to type C counteracts such a pressure rise so that a higher yield of ultraviolet radiation must be obtained.

For sufficiently small lead resistance in which the discharge is substantially only determined by the tube itself, apparently plasma oscillations occur in the tube with high currents and probably high current densities which also favour the emission of optically effective radiation.

It has been shown that the described oscillations are not oscillations of an oscillatory circuit comprised of tube and storage capacitor, as their frequency is not changed in an otherwise to be expected manner either by a change in the capacity of the storage capacitor or by an additional inductance in the discharge circuit. A phenomenon of oscillation in the tube itself is apparently involved.

The invention is claimed as follows:

1. A short-wave light flash-generator for photochemical treatment by a continuous series of distinct high-surge flashes, including a storage capacitor and an electron flash tube, of ultraviolet transmitting material, ignitable by means of an ignition electrode to discharge the storage capacitor through a discharge circuit in series with the flash tube, and having circuitry for connection to an A.C. power source for charging said storage capacitor and energizing said ignition electrode to produce a series of time-separated flashes at a frequency from half to double the power source frequency, characterized in that:

the discharge circuit has a resistance substantially below 0.1 ohm and so low that the peak current of the discharge is substantially determined only by the flash tube.

2. A short-wave light flash-generator for photochemical treatment by a continuous series of distinct high-surge flashes, including a storage capacitor and an electron flash tube, of ultra-violet transmitting material, ignitable by means of an ignition electrode to discharge the storage capacitor through a discharge circuit in series with the flash tube, and having circuitry for connection to an A.C. power source for charging said storage capacitor and energizing said ignition electrode to produce a series of time-separated flashes at a frequency from half to double the power source frequency, characterized in that:

the discharge circuit has a resistance substantially below 0.1 ohm and so low that the successive discharges through the tube are characteristic of substantially undamped condenser discharges in being heavy surges of substantially shorter duration than the time available as determined by the frequency of the flashes.

3. A short-wave light flash-generator for photochemical treatment by a continuous series of distinct high-surge flashes, incuding a storage capacitor and an electron flash tube, of ultraviolet transmitting material, ignitable by means of an ignition electrode to discharge the storage capacitor through a discharge circuit in series with the flash tube, and having circuitry for connection to an A.C. power source for charging said storage capacitor and energizing said ignition electrode to produce a series of time-separated flashes at a frequency from half to double the power source frequency, characterized in that:

the discharge circuit has a resistance substantially below 0.1 ohm so low that the peak current of the discharge is substantially determined only by the flash tube; and

the flash tube has a tubular discharge channel of a relatively small internal diameter which is not filled completely by the discharge, and that the discharge channel is open to dead spaces on both sides of larger internal diameter, each of which has a volume at least equal to the volume of the discharge channel.

4. A short-wave light flash-generator for photochemical treatment by a continuous series of distinct high-surge flashes, including a stroage capacitor and an electron flash tube, of ultraviolet transmitting material, ignitable by means of an ignition electrode to discharge the storage capacitor through a discharge circuit in series with the flash tube, and having circuitry for connection to an A.C. power source for charging said storage capacitor and energizing said ignition electrode to produce a series of time-separated flashes at a frequency from half to double the power source frequency, characterized in that:

the discharge circuit has a resistance substantially below 0.1 ohm and so low that the peak current of the discharge is substantially determined only by the flash tube; and

the flash tube has a tubular discharge channel of an internal diameter of less than 5 mm which is not filled completely by the discharge, and that the discharge channel is open to dead spaces on both sides of larger internal diameter, each of which has a volume at least equal to the volume of the discharge channel.

* * * * *