Jan. 25, 1955 J. H. PARK 2,700,743

INTENSIFICATION OF AN ELECTRON BEAM FROM COLD-CATHODE DISCHARGE

Filed Oct. 5, 1951

2 Sheets-Sheet 1

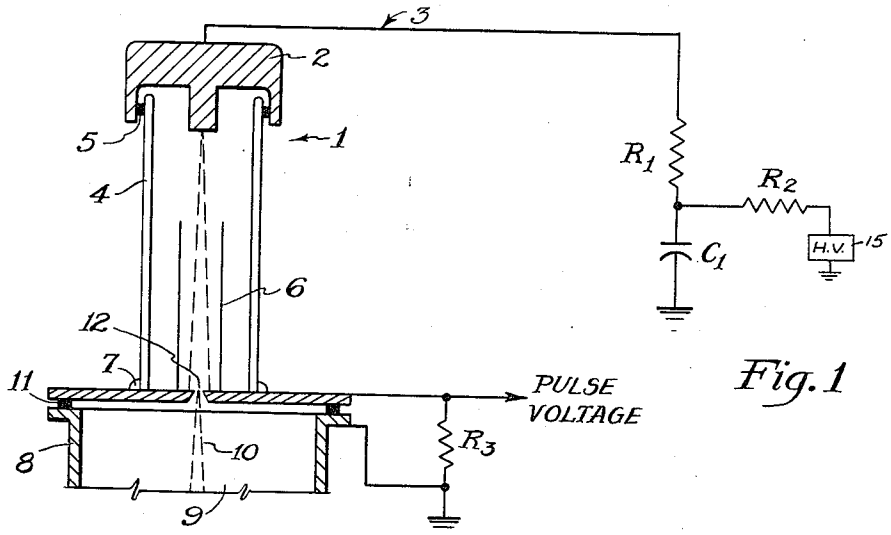


Fig. 1

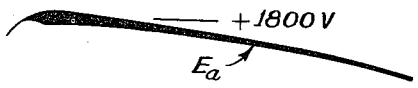
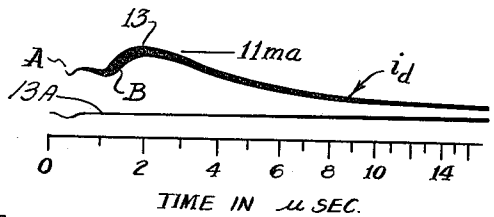


Fig. 2



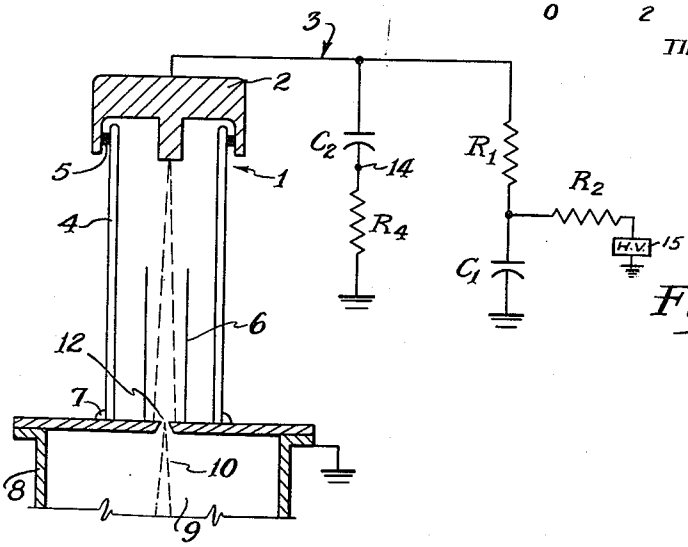


Fig. 3

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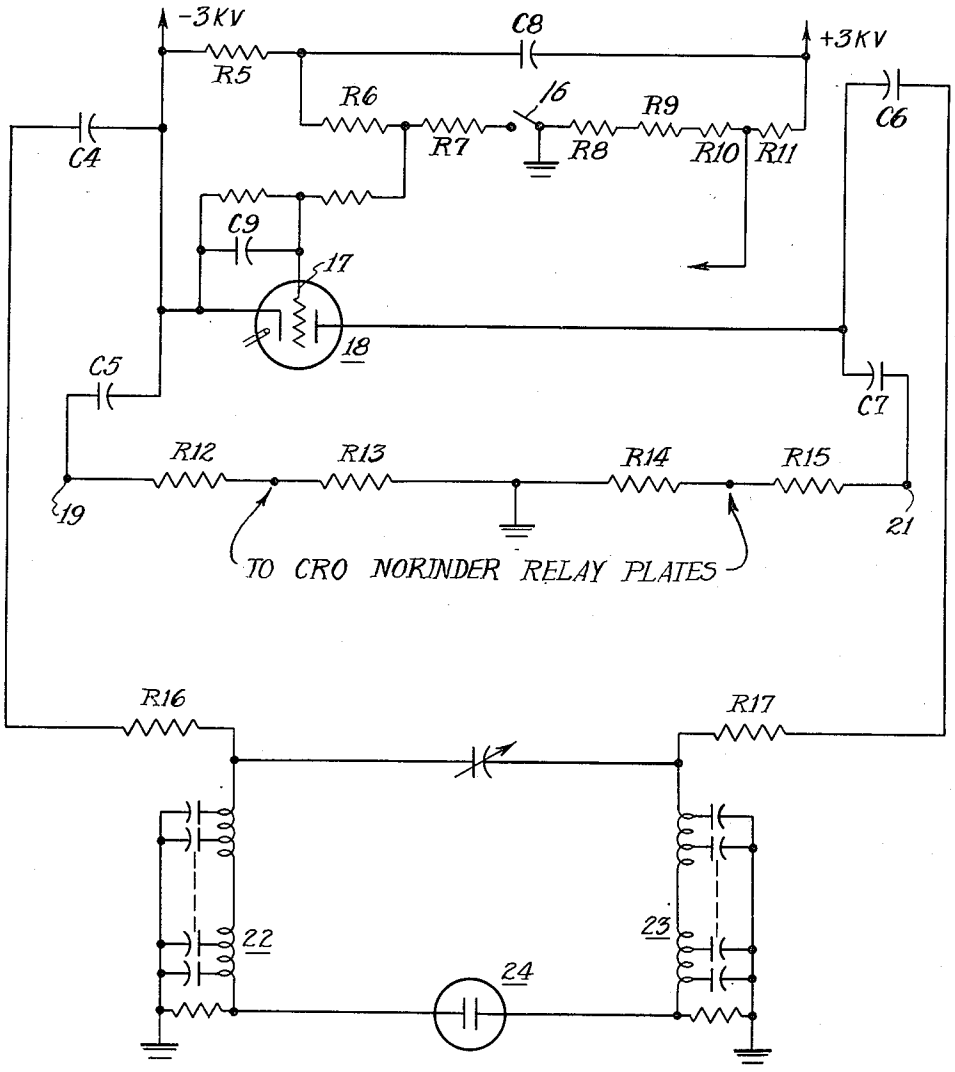


Fig. 4

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INTENSIFICATION OF AN ELECTRON BEAM FROM COLD-CATHODE DISCHARGE

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6 Claims. (Cl. 315—30)

(Granted under Title 35, U. S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government of the United States for governmental purposes without the payment to me of any royalty thereon in accordance with the provisions of the act of March 3, 1883, as amended (45 Stat. 467; 35 U. S. C. 45).

The present invention is concerned with the momentary intensification of an electron beam obtained from a high-voltage cold-cathode discharge tube and more specifically is concerned with intensifying the electron beam for a few microseconds so that very rapid electrical transients may be photographed.

High-voltage cold-cathode discharge tubes have long been used as a source of electron beams. Probably their most important application has been to supply the electron beam for high-speed cathode-ray oscillographs which are used in the recording of transient electrical phenomena of short duration. In the past it has been very difficult to obtain photographic records of some of the shorter transients. The speed at which an electron beam must be deflected to follow the transients of such short duration is very great and in the past it has not been possible to obtain a beam of sufficient intensity to affect photographic papers while being deflected at such high speeds.

A number of attempts have been made in the past to obtain a beam of sufficient intensity by shaping of the electrodes, using different gases in the discharge tube and using prefocusing coils placed around the discharge tube. However, to date the normal maximum writing speed for such oscillographs has been about 200 inches per microsecond.

The primary object of this invention is to provide a cathode-ray oscillograph with an electron beam of sufficient intensity to allow oscillographs to be made of very short duration electrical transients.

Another object of the invention is to provide a cathode-ray oscillograph with an electron beam with a very high writing speed.

Still another object is to provide an electron beam capable of affecting photographic papers at a writing speed of approximately three-fourths the speed of light.

Still another object of the invention is to provide for a momentary intensification, of 50 to 60 times, of an electron beam emitted by a high-voltage, cold-cathode discharge tube.

Another object is to provide a large momentary intensification of the electron beam while suppying only a comparatively small increase in anode potential.

Another object of this invention is to provide an electron beam of sufficient intensity to record on photographic papers electrical transients lasting two microseconds or less.

Another object is to provide a high-voltage cold-cathode discharge tube having an electron beam of sufficient intensity to allow photographic records to be made at writing speeds of approximately 9,100 inches per microsecond.

In accordance with the present invention the electron beam discharge in a cold-cathode discharge tube is greatly intensified for a short period by superimposing a voltage pulse of about 2 percent of the cathode-to-anode voltage on either the anode or the cathode.

Other uses and advantages of the invention will become apparent upon reference to the specification and drawings.

Figure 1 is a circuit diagram of one form of the invention.

Figure 2 is a copy of an oscillogram showing the time lags involved in the present invention.

Figure 3 is a circuit diagram of another form of the invention.

Figure 4 is a circuit diagram of the modified cathode-ray oscillograph voltage supply.

Referring now to Figure 1, the discharge section of the high-voltage cold-cathode discharge tube which may be of the type shown in United States Patent No. 1,910,560 is shown at 1. The cathode 2 is connected by wire 3 through the resistors R1 and R2 to the negative high-voltage supply 15. The junction between R1 and R2 is grounded through the condenser C1. The discharge section is enclosed in a glass envelope 4 which is sealed into the cathode by rubber gasket 5 and is sealed to the anode 6 at 7. Before modification for purposes of the present invention the anode 6 was fastened directly to the all metal outer casing 8 of the cathode-ray oscillograph chamber 9 and was therefore grounded. However, after modification for reasons to be explained later, the anode 6 is electrically insulated from the outer casing 8 by the insulator 11. The anode 6 is then connected to ground through resistor R3.

The operation of the device is as follows: With 40 to 60 kilovolts direct current applied between the cathode 2 and the anode 6 and the pressure adjusted to approximately 5 to 10 microns of mercury, a fine pencil line discharge is obtained originating in a bright spot at the center of the cathode. By regulating the conditions in the discharge region, the discharge current can be made to have a value of from 0.1 to 0.8 milliampere. About one percent of the cathode current passes through the small hole 12 in the center of the anode 6 into the main chamber 9 forming the electron beam 10. Here the beam passes through the usual beam trap, focusing coils, deflecting and sweep plates, and finally strikes the film. None of these are shown in Figure 1 and they form no part of the present invention. The transient to be studied is applied to one set of the deflection plates and causes a deflection of the electron beam, a sweep voltage being applied to the other set of deflection plates, thus leaving a trace on the film which is in effect a plot of voltage against time for the transient. As previously pointed out, it has been very difficult in the past to obtain an electron beam of sufficient intensity to leave a trace on the film when moving at very high speeds. To overcome this in accordance with the present invention a very brief positive current pulse is passed through resistor R3 to ground. The current pulse is only large enough to increase the voltage from cathode to anode by from 800 to 2500 volts over the existing 50 kilovolts. However, this causes a beam intensification of up to 50 times normal intensity. The increased beam intensification lasts for a very short time (about 2 microseconds) and therefore does not appreciably increase the burning of the cathode.

When the voltage pulse is applied to the anode the discharge current increases to a high value immediately. Beam intensification and another increase in discharge current occur a short time later.

This can be seen clearly with reference to Figure 2. The zero current line 13A was made with a beam of normal intensity. At zero time an 1800-volt positive pulse was applied to the anode 6 in a manner to be described later. The current, as shown by trace 13, increased immediately to 7 milliamperes as shown at A, but the electron beam was not intensified. However, within less than 0.5 microsecond the current again increased (11 ma.), as shown at B, but this time the electron beam was greatly intensified. This is shown by the fact that the trace 13 is very thick and bright at this point. The voltage pulse was only 1800 volts and therefore this trace is used to show typical rather than optimum results.

The delay between the application of the voltage pulse and the desired beam intensification is dependent upon two factors. One is the magnitude of the voltage pulse and the other is the initial electron beam current. At present, delays of only 0.25 microsesecond have been obtained. This very short delay can be obtained if a pulse of 2500 volts is used regardless of how low the initial value of the beam current is. On the other hand if a voltage pulse of 800 volts is used, a delay of only 0.25 microsecond cannot be obtained no matter how large the initial beam current.

Figure 3 shows a circuit used to apply a negative voltage pulse to the cathode. This type of operation also increases the cathode-to-anode voltage and the results obtained are identical with those obtained when the anode is pulsed.

In this modification the anode is grounded and therefore the special insulator **11** used in the modification of Figure 1 can be eliminated. However, here the resistor R1 and capacitor C1 are shunted by the capacitor C2 and resistor R4.

With the steady direct-current voltage on the cathode the capacitor C2 is charged to 50 kilovolts. By passing a current through the resistor R4 from ground to point **14**, the point **14** becomes negative with respect to ground. This decreases the cathode voltage and increases the cathode-to-anode voltage.

It will be noted that beam intensifications of up to 50 times are obtainable with sudden increase in cathode-to-anode voltage of only 2 percent. As a possible explanation of this phenomenon consider the variation of net space charge density in the discharge between the cathode and anode. There is a high concentration of both electrons and positive ions throughout the volume of the discharge. Electrons are being constantly fed into the region near the cathode, and since it takes a definite, even though short, time for them to be accelerated toward the anode by the impressed electric field, a large negative space charge region is built up near the cathode. In the region near the anode, including the space inside the tube forming part of the anode, gas molecules are continually being ionized by the short wave radiation produced by the impact of high speed electrons on the anode. The slow electrons produced in this manner drift toward the anode and leave an excess of positive ions which tend to be accelerated toward the cathode but in the meanwhile build up a high net positive space-charge region near the anode.

Under steady-state conditions with 50 kilovolts direct current applied between the cathode and anode and with normal electron beam, it may be assumed that the high concentration of negative space charge in the region near the cathode makes the gradient at the cathode quite small in comparison to the average gradient between electrodes. Similarly the gradient near the anode should be quite small though of opposite sign. It must be kept in mind with respect to both of these space charge regions that although they have a definite sign they both contain particles of the opposite sign in each region. That is, the negaive space charge around the cathode contains many positive ions and the positive space charge contains many electrons. When the voltage between cathode and anode is suddenly increased, an instantaneous change in charge can occur only on the electrode surfaces. Since the electrode more nearly approximate points rather than infinite planes, the sudden change in their surface charge causes a sudden increase in gradient mainly in the regions near the electrode. The sudden increase in gradient causes electrons from the positive space charge and respective positive ions from the negative space charge to be drawn from each space charge region toward the respective adjacent electrodes. This flow of electrons and ions constitutes a current flow in the external supply circuit which is superposed on the steady state current in the discharge tube. Electrons and ions flow in a direction to increase the negative space charge density in the cathode region and to increase the positive space-charge density in the anode region. This is illustrated by the first part of the trace **13** in Figure 2. A sudden increase of available electrons in the space near the cathode, if it is of sufficient magnitude, will disrupt the equilibrium conditions existing in the discharge as shown in Figure 2 by the second increase in discharge current accompanied by beam intensification. A possible explanation of this sudden change in equilibrium conditions in the discharge is as follows: The increase of negative space charge in the region near the cathode causes an increase (probably gradual at first) in magnitude of the electron stream from cathode space-charge region to anode space-charge region. The greater the number of fast electrons reaching the anode the greater will be the supply of positive ions; and they will be accelerated toward the cathode and produce more electrons. Thus the action is cumulative. If the initial change is small or occurs at a low rate, a new equilibrium condition will be attained with little effect on the electron beam. If the initial disturbance is of sufficient magnitude and occurs suddenly, the cumulative effect causes beam intensity and discharge current to increase rapidly (see Figure 2). This effect is stopped very soon because the number of positive ions that can be produced in this short time is limited by the low gas pressure (total number of gaseous molecules) in the tube. As the number of available positive ions is reduced, the beam intensity and discharge current gradually decrease and in some cases the discharge is momentarily extinguished.

Figure 4 is a wiring diagram of the circuits used to supply the current pulses necessary to produce the required voltage pulse that is to be applied to the anode or cathode of the tube. The cathode-ray oscillograph employed in the beam intensification studies uses a pulse source to supply the Norinder relay or beam unblocking plates. Since this supply is always available it is convenient to use it for the pulse supply to the discharge electrode although it is not necessary to do this. Another source of voltage could be used.

When the −3 kilovolt and +3 kilovolt sources are energized the capacitors C4, C5, C6, and C7 become charged. The condenser C8 is charged through resistors R5 and R8 through R11. The grid **17** of gas tube **18** is held at the same potential as the negative plate of capacitor C8 which is −3 kilovolts after C8 becomes fully charged. When the switch **16** is closed, capacitor C8 discharges through resistors R6 to R11, causing the junction between R10 and R11 to go positive. This positive pulse is used to trigger the phenomenon to be studied. At the same time the potential of the junction between resistors R6 and R7 becomes less negative which after a short time delay produced by C9 fires the tube **18**. This closes the circuit including tube **18**, capacitors C5 and C7 and resistors R12, R13, R14, and R15. The capacitors C5 and C7 are discharged and produce a large voltage pulse across resistors R12, R13, R14, and R15. As indicated in Figure 4, this voltage supplies the Norinder relay plates. This pulse is also used to supply the 800 volts to 2500 volts for the cathode or anode of the discharge tube and is taken off at either point **19** or point **21**. The pulse taken from point **19** is positive and therefore would be connected to the resistor R3 of Figure 1. The pulse taken from point **21** is negative and therefore would be applied across resistor R4 of Figure 3.

When the tube **18** fired, the capacitors C4 and C6 were also discharged. They discharged through a path consisting of tube **18**, resistors R16 and R17, delay lines **22** and **23**, and ground.

This circuit gives positive synchronization of the beam intensification with the sweep and the Norinder relay voltage, but since the time to attain maximum intensification is about 0.25 microsecond, delay lines of 0.25 microsecond must be inserted in the supply to the sweep plates **24**. This delay in sweep supply has the added advantage of allowing the voltage on the Norinder relay plates to reach a high uniformly changing value before the sweep is started, which is quite important for very short sweep times.

It will be noted that the only modification necessary in the voltage supply circuit was the addition of the delay lines. The only other modifications necessary were the addition of an insulating ring and a resistor in Figure 1 or the addition of a resistor and capacitor in Figure 3. In accordance with the present invention it has been possible to obtain beam intensifications up to 50 times normal intensities by means of the minor modifications pointed out above.

It will be apparent that the embodiments shown are only exemplary and that various modifications can be made in construction and arrangement within the scope of my invention as defined in the appended claims.

I claim:

1. A circuit for intensifying the electron beam of a cold-cathode discharge tube comprising a cold cathode, an anode with a small hole in the center, means for applying a direct-current voltage of from 40 to 60 kilovolts between said anode and said cathode, means for intensifying said electron beam including a source of pulse voltage of from 800 to 2500 volts and means for applying said pulse voltage so as to increase the anode to cathode voltage.

2. A circuit for intensifying the electron beam of a

cold-cathode discharge tube comprising a cold cathode, an anode with a small hole in the center, means for applying a direct-current voltage of from 40 to 60 kilovolts between said anode and said cathode, means for intensifying said electron beam including a source of pulse voltage of from 800 to 2500 volts and means comprising resistor means for applying said pulse voltage so as to increase the anode-to-cathode voltage.

3. A circuit for intensifying the electron beam of a cold-cathode discharge tube comprising a cold cathode, an anode with a small hole in the center, a resistor connected from said anode to a point of zero potential, a negative direct-current voltage source of from 40 to 60 kilovolts connected between said point of zero potential and said cold cathode and means for intensifying said electron beam including a source of positive pulse voltage of from 800 to 2500 volts connected across said resistor.

4. A circuit for intensifying the electron beam of a cold-cathode discharge tube and for recording very short duration electrical transients comprising a cold cathode, an anode with a small hole in the center, a resistor connected from said anode to a point of zero potential a negative direct-current voltage source of from 40 to 60 kilovolts connected between said point of zero potential and said cold cathode, means for intensifying said electron beam including a source of positive pulse voltage of from 800 to 2500 volts connected across said resistor and means for applying a pulse across said resistor in timed relation with the electrical transient.

5. A circuit for intensifying the electron beam of a cold-cathode discharge tube comprising a cold cathode, an anode with a hole in the center, said anode being connected to a point of zero potential, a large negative voltage source connected between said cathode and the

point of zero potential, a resistor and a condenser connected in series, said condenser also being connected to said cathode and said resistor also being connected to said point of zero potential and a source of negative pulse voltage connected across said resistor.

6. A circuit for intensifying the electron beam of a cold-cathode discharge tube to record very short duration electrical transients, comprising a cold-cathode discharge tube having a cold cathode and an anode with a small hole in the center, means for applying a constant direct-current voltage of from 40 to 60 kilovolts between said anode and said cathode to produce an electron beam of substantially constant value, means for intensifying the steady-state electron beam by a factor of approximately fifty, said means including a source of pulse voltage having an amplitude equal to about 2 to 4 percent of the initial anode-to-cathode voltage, and means for applying said pulse voltage so as to increase the anode-to-cathode voltage in timed relation with the electrical transient to be recorded.

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