May 7, 1957 J. O. EKBLOM ET AL 2,791,724

SWITCHING CIRCUIT

Filed July 31, 1953 2 Sheets-Sheet 1

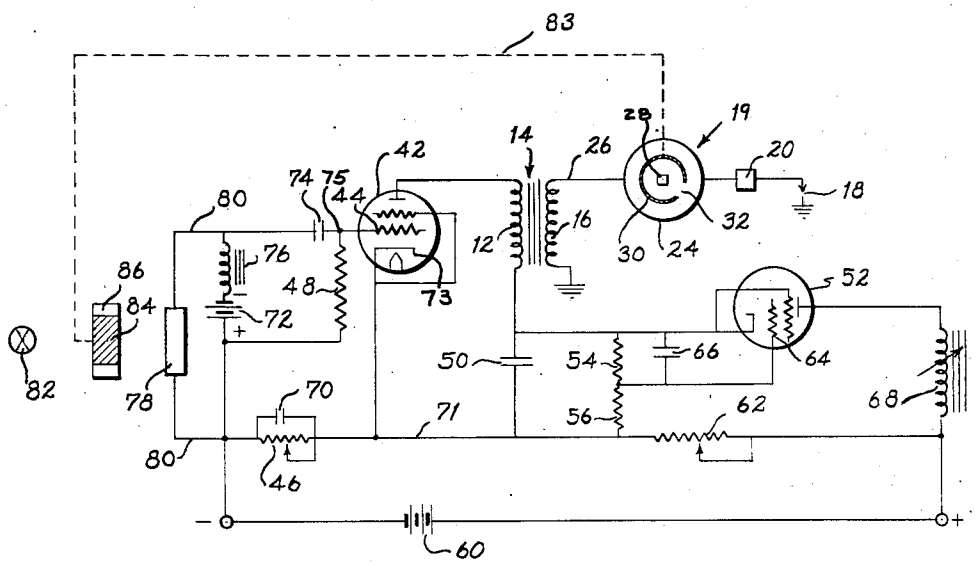


Fig. 1

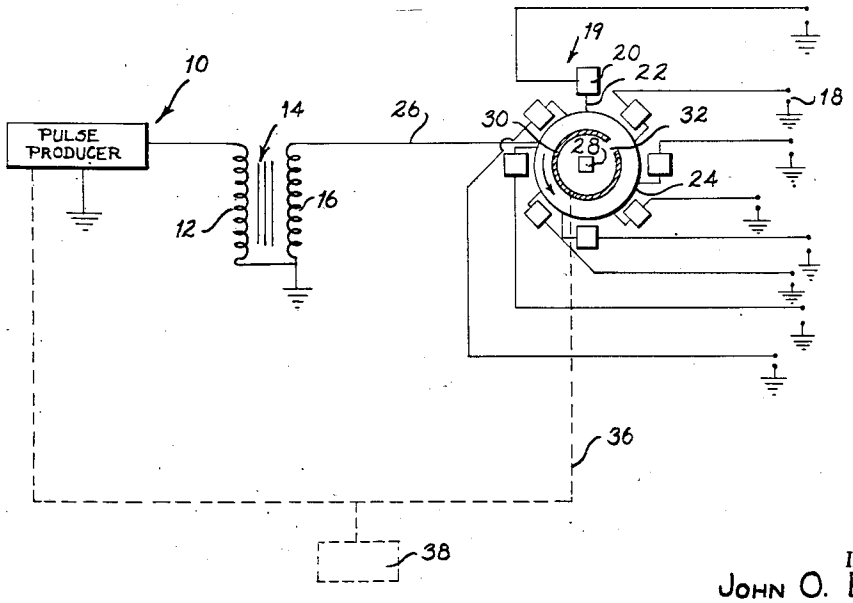


Fig. 2

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Filed July 31, 1953 2 Sheets-Sheet 2

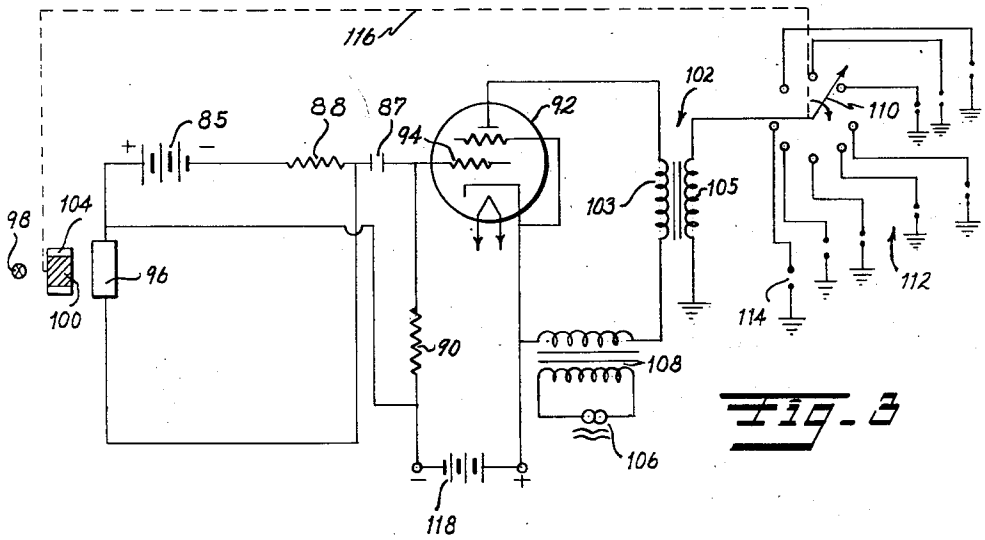


Fig. 3

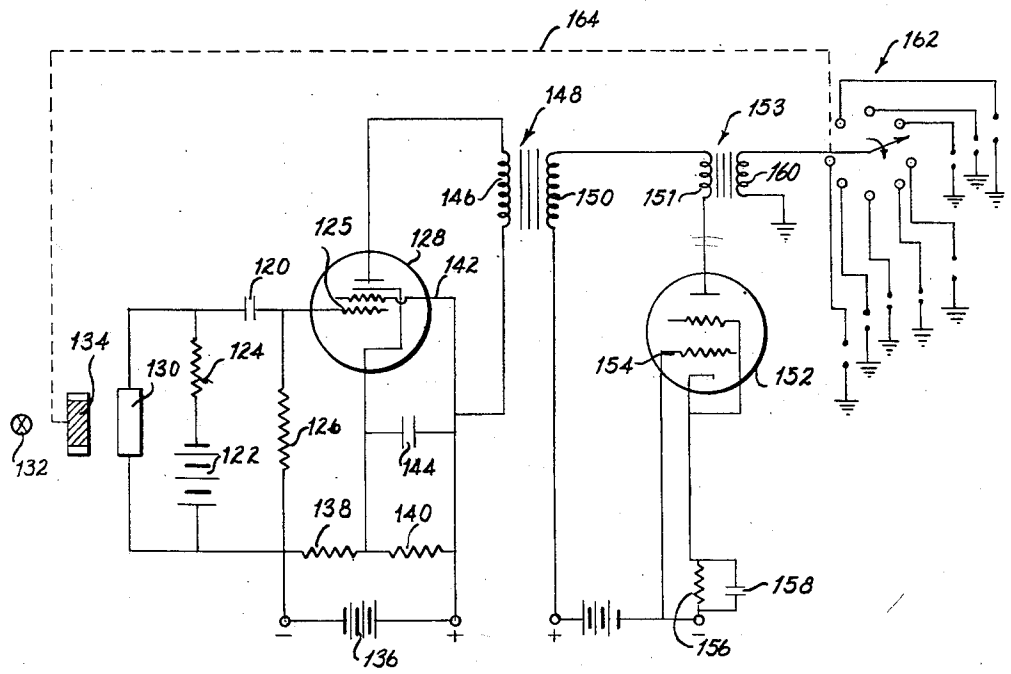


Fig. 4

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SWITCHING CIRCUIT

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Application July 31, 1953, Serial No. 371,668

17 Claims. (Cl. 315—153)

The present invention relates to ignition systems for internal combustion engines, and more particularly to improvements so that the production and distribution of pulses of electrical energy are accomplished without the use of moving contacts.

In the prior art ignition systems for internal combustion engines it has become the general practice to provide a low voltage, high current, primary circuit interrupted by a cam operated switch, and inductively coupled to a high voltage, low current secondary circuit provided with a rotating contact arm sequentially establishing electrical contact with the spark plug circuits of the several cylinders of the engine.

In such systems of the prior art there is troublesome deterioration of the contact points of the switch in the primary circuit, and improper operation of the ignition system is caused by faulty operation of the high tension distributor due to the burning of contacts and due to the presence of dirt and moisture.

To overcome these disadvantages of the prior art ignition systems, it is a fundamental object of the present invention to provide an ignition system in which pulses of electrical energy are produced and distributed to the several spark plugs without the use of moving contacts.

It is a further important object of this invention to provide an ignition system in which the initiation and termination of primary current flow is controlled by a radiation sensitive element intermittently rendered conductive by radiant energy.

It is a further important object of the present invention to provide an improved ignition system having a high tension current distributing device effective to sequentially connect a series of spark plugs, or like spark gap devices, into the high tension circuit without the use of moving contacts. More specifically it is an object of this invention to provide an improved ignition system in which the distribution of the high tension current is effected by the sequential stimulation of a series of radiant energy responsive elements from an associated source of radiant energy, and with each radiant energy responsive element connected to an individual spark gap device.

It is a further important object of this invention to provide an improved ignition system in which novel means are provided for the production of pulses of electrical energy.

These and other objects of the present invention will become more fully apparent by reference to the appended claims and as the detailed description of the invention proceeds with reference to the accompanying drawings, wherein:

Figure 1 is a diagrammatic showing of the electrical circuits and components of the ignition system of the present invention;

Figure 2, is a diagrammatic showing of the high tension distributor means of the present invention and associated pulse producing means; and

Figures 3 and 4 are diagrammatic showings of modified pulse producing means of the present invention.

Referring to Figure 2, a conventional device, indicated generally at **10**, produces regularly recurring electrical pulses which are fed to a primary winding **12**, of a suitable step-up transformer **14**, so that pulses of high voltage appear at the terminals of a secondary winding **16**, of the transformer.

A plurality of spark plugs **18**, are connected to the transformer **14**, through a novel high tension distributor means, indicated generally at **19**, and are installed on the cylinders of an internal combustion engine (not shown) to effect ignition of the gaseous mixture in the cylinders in the conventional manner. The novel high tension distributor means comprises a group of photoconductive cells **20**, arranged in a circle, and each cell is connected by a wire **22**, to a spark plug individual to the cell, and each cell is also connected to a common wire or bus **24**, which is connected by a wire **26**, to the secondary of the transformer. A source of light **28**, is disposed in a revolvable casing **30**, and a slot **32**, is provided in a wall of the casing, so that as the casing is revolved each cell is illuminated as the slot passes in front of it, and is otherwise in the "dark" condition. As is indicated by the dotted line **36**, the casing is moved in timed relation to the production of the pulses and the production of the pulses is synchronized with the positioning of the slot before a cell by a common driving means **38**, on the engine to which the ignition system is applied. The slot **32**, is shaped so that each cell is illuminated suddenly and darkened suddenly so that each cell becomes conducting and non-conducting, respectively, to bring about a result analogous to the closing and opening of a switch but without sparking contacts in the distributor.

The cells are formed of one of the binary compounds and of which cadmium sulfide is preferred, and it is characteristic of the cadmium sulfide cell that its internal resistance drops suddenly to an adequately low value when the cell is suddenly illuminated by a light of high intensity, and that its internal resistance returns to an adequately high value when the illumination is removed so that for many practical purposes the cell may be thought of as a non-conductor when dark. The structure and method of formation of such cells is disclosed in copending application Serial No. 329,973 filed January 7, 1953, by Leonard E. Ravich, for "Semi Conductor Improvements and Devices for Use of Same." The term "dark" is used in the sense in which it is used by those familiar with the application of photosensitive or other radiation sensitive means, and does not mean the complete absence of light or other radiant energy. The cells **20**, are each provided with adequate conducting surface so that they are of adequate current carrying capacity for carrying the current to the spark plugs without undue energy loss.

If the spark plugs are of the now conventional shielded type there is nothing in the high tension distributor **19**, to cause radio interference, and with the absence of moving switch arms, the possibility of the distributor producing radio disturbances is avoided. This is of first importance to the armed services for the distributor will not disclose the presence of a vehicle or ship on which it is applied.

Referring now to Figure 1, which shows an ignition system provided with novel means for producing recurring electrical pulses of high voltage. A first gas discharge tube **42**, at a certain assumed instant, is in the non-conducting condition because of the normal bias on its control grid **44**, produced by a bias resistor **46**, in its grid-cathode circuit, and connected to the grid through a control resistor **48**, and getting current through a wire

71, from a battery 60, through a circuit which includes the bias resistor and a resistor 62, which, in one circuit arrangement, is of the order of twenty thousand ohms. At the assumed initial instant, the anode-cathode circuit is at full voltage because a capacitor 50, in this circuit is fully charged to substantially the voltage of the battery 60.

A second gas discharge tube 52, is also non-conducting because its control grid 64, is biased by the voltage across a resistor 54, shunted by a capacitor 66, as the capacitor 50, bleeds slowly through a voltage divider network of resistors 54 and 56 connected to the terminals of the capacitor 50. Since the capacitor 50, is assumed to be fully charged at the instant considered, about one-fourth of its voltage will appear across the resistor 54, and the capacitor 66.

The resistor 62, may be considered a component of a voltage divider circuit which includes the resistor 46, and the connecting wire 71 is the negative connection for the cathode 73 of tube 42, and for the negative pole 75, of the capacitor 50. The time-constant of the circuit which includes the capacitor 50, and the voltage divider network is large compared to the period during which the capacitor remains charged in the normal operation of the pulse producing means, so the capacitor may be fairly said to be fully charged at the assumed initial instant.

If, now, a sharp pulse of the proper voltage and of the proper polarity is applied in the grid-cathode circuit of the first tube 42, this tube will instantaneously become conducting. The capacitor 50, is connected in the plate-cathode circuit of the tube 42, in series with the primary winding 12, of the transformer 14, and with the heavy rush of current through the tube when it becomes conducting a pulse of high voltage appears at the terminals of the secondary winding 16, of the transformer. The capacitor 50 is substantially isolated at the instant of discharge from the positive pole of the battery 60 by the resistor 62. When the capacitor 50, is substantially discharged the plate voltage of the tube 42, drops to a low value so that the control grid 44, regains a control, and the tube becomes again non-conducting.

As the capacitor 50 becomes substantially discharged, the small capacitor 66, across the terminals of the resistor 54, discharges slowly through this resistor, and the second tube 52, becomes conducting to connect the capacitor 50, to the positive pole of the battery 60, to charge the capacitor. The path of the charging current is through the tube 52, through the capacitor 50, and through the bias resistor 46, to the negative pole of the battery. This path is of relatively low resistance, and the instantaneous current would be large, but for the fact that this instantaneous current is limited by an inductance 68, connected in series in the plate circuit, and having a low resistance so that the energy loss is low. It has been observed that one effect of this inductance is to materially sharpen the charging current pulse of the capacitor 50, as distinguished from the shape of the pulse if a resistor was inserted in lieu of the inductance as current limiting means. As the capacitor 50, charges through the bias resistor 46, it charges the capacitor 70, connected in shunt with the resistor 46, and there is a temporary high bias voltage established in the control grid circuit of the tube 42. This temporary high bias voltage is useful in preventing unwanted firing of tube 42, while the second tube 52, is conducting, and so avoids possible accidental destruction of the two tubes. The capacitor 70, discharges through the resistor 46, and the bias of the control grid of the first tube 42, returns to normal when the capacitor 50, attains practically full charge. When the capacitor 50, becomes practically fully charged the plate current of the second tube 52 becomes so low that the bias voltage now appearing across the resistor 54, enables the control grid 64, to take control and to render the tube 52, non-conducting, so that the system is now ready to accept a pulse at the control grid of the first tube 42.

A battery 72, is arranged to charge a capacitor 74

through a circuit which includes the battery, an inductance 76, the capacitor, and the grid control resistor. A cadmium sulfide photoconductive cell 78, is connected in parallel with the charging circuit by wires 80, and when this cell is "dark" its internal resistance is so high that it does not interfere with the charging of the capacitor. A light or other suitable radiant energy source 82 such as tritiated stilbene is disposed in front of the cell, and a revolvable obscuring disc or shutter 84, is disposed between the light source and the cell. The shutter is revolved in synchronism with the casing 30 of the high tension distributor 19, described in connection with Figure 2, so that slots 86, in the shutter 84, expose the cell 78, to a burst of light at the instant that a cell 20, is being made conductive in the high tension distributor 19. When the cell 78, becomes illuminated its resistance drops to a relatively very low value so that the capacitor 74, now quickly discharges through a discharging circuit which includes the cell 78, the capacitor, and the resistor 48, and since the resistor 48 is in the grid-cathode circuit of tube 42, the voltage developed across it by the discharge current causes the tube 42 to become conducting. When the tube 42, becomes suddenly conducting a pulse of high voltage appears at the terminals of the secondary winding of the transformer 14, in the manner already described.

The dotted line 83 is used to indicate that the shutter 84, is connected with the casing 30, of the high tension distributor by suitable means to get the desired synchronizing of the light flashes.

The illuminating of the cell 78, is comparable to the "break" in the primary circuit of the conventional ignition system in that it results in the pulse of current from the capacitor 74, to make the tube 42, conducting to get the spark, and the darkening of the tube is comparable to the "make" in the primary circuit of the conventional ignition system in that it permits energy being stored in the capacitor. However, in the present ignition system there are no moving parts in the electrical circuit, and no moving current-carrying switch parts to be affected by burning, dirt and moisture.

In the pulse producing means shown in Figure 3, a capacitor 87, is charged by a battery 85 in a circuit which comprises the battery, the capacitor, a resistor 88, and a grid controlling resistor 90, in the grid-cathode circuit of a gas discharge tube 92, and with a control grid 94, of the tube connected at the junction of the capacitor to the controlling resistor. A photoconductive cell 96, of cadmium sulfide or another suitable binary compound, has a high resistance when dark, and a relatively very low resistance when illuminated, and when illuminated it effects the discharging of the capacitor through a discharging circuit which comprises the capacitor, the cell, and the controlling resistor 90. A light source 98, is disposed in front of the cell, and a revolvable wheel or shutter 100, is interposed between the light source and the cell and is provided with slots 104, shaped to effect a sharp pulse of illumination and a sharp cut-off.

A suitable source 106, of alternating current, feeds the plate-cathode circuit of the tube through a suitable transformer 108, and the primary winding 103 of a step-up transformer 102, is inserted in the plate-cathode circuit, and the secondary winding 105 of the transformer may be connected to the revolving contact arm 110, of a conventional high tension distributor 112, to the spark plugs 114, of the internal combustion engine to which the system is applied. As indicated by the dotted line 116, the revolving wheel or shutter 100, is synchronized with the revolving arm 110. The tube is suitably biased by a battery 118, in the grid-cathode circuit of the tube to be non-conducting while the capacitor 87 is charging, and when the cell 96, becomes suddenly illuminated, the discharging current of the capacitor through the control resistor 90, produces a bias of the right value to cause the tube to become suddenly conducting if the plate of the tube is positive. The frequency of the alter-

nating current source should be at least twice the frequency at which the "firing" impulses are received at the control grid **94**, and the time constant of the capacitor discharging circuit should have a minimum value equal to one complete cycle of the alternating current supplied by the source **106**.

The control grid **94**, usually gains control of the firing of the tube when the plate becomes negative, but if the time constant of the grid circuit is high enough current may flow through the tube over more than one positive half cycle, and more than one spark may appear at the spark plug at the top of each piston ignition stroke. However, these sparks are very close together in time, and a short train of sparks following a single activating pulse at the control grid of the tube is not objectionable, since the sparks would occur while the contact arm of the conventional distributor was still in connection with a single spark plug.

In the pluse producing means shown in Figure 4, a capacitor **120**, is charged by a battery **122**, in a charging circuit which comprises the capacitor, the battery, a resistor **124**, and a grid controlling resistor **126**, of a beam power tetrode tube **128**. A control grid **125**, of the tube is connected to the junction of the capacitor and the control resistor **128**.

A photoconductive cell **130**, is disposed in front of a light source **132**, and a revolving wheel or shutter **134**, similar to those already described, is provided to alternately illuminate and darken the cell. The cell is of cadmium sulfide, or of another suitable binary compound, and has a high ohmic resistance when dark, and a very low resistance when adequately illuminated. When the cell is illuminated suddenly its resistance drops suddenly and it causes the discharging of the capacitor **120**, through a discharging circuit which comprises the capacitor, the cell, and the grid controlling resistor **126**, and the voltage developed across the resistor **126**, causes the tube **128** to become conducting. The tube is normally biased to near cut-off condition by a battery **136**, connected to a voltage divider having a portion **138**, in the grid-cathode circuit of the tube, and a portion in the circuit connecting a screen grid of the tube with the cathode of the tube, and shunted by a capacitor **144**.

A primary winding **146**, of a pulse transformer **148**, is connected in the plate circuit of the tetrode **128**, and a secondary winding **150**, of the pulse transformer is inserted in the plate circuit of the gas discharge tube **152**, in series with a primary winding **151**, of a step-up transformer or spark coil **153**. The secondary winding **150**, is so connected in the plate circuit of the tube **152**, that when the tetrode **128**, becomes suddenly conducting there is a pulse of voltage injected in the plate circuit of the tube **152**, opposing the plate voltage to assist in momentarily changing the tube **152**, from the conducting to the non-conducting condition.

At the instant at which the plate voltage of the tube **152**, drops because of the opposing voltage from the pulse transformer, a control grid **154**, gains control of the tube to render it non-conducting because of the bias voltage available through a bias resistor **156** in the grid-cathode circuit, and shunted by a capacitor **158**. The sudden interruption of the plate current of the tube **152**, results in a sudden collapse of the magnetic field of the spark-coil **153**, and a pulse of high voltage appears at the terminals of a secondary winding **160**, of the spark coil.

With the termination of the pulse from the pulse transformer **148**, and the subsequent increase in the plate voltage of the tube **152**, the control grid **154**, loses control, and the tube **152**, begins to conduct again with the increase in its plate current somewhat delayed by the inductance of the primary winding of the spark coil **153**.

The output of the transformer **153**, is fed to the spark plugs of the internal combustion engine through a suitable high tension distributor, indicated generally at **162**, and, as in the ignition systems hereinbefore described the movement of shutter **134**, is synchronized with the distributing means in the distributor **162**, as indicated by the dotted lines **164**.

While the pulse producing means hereinbefore described are peculiarly adapted to meet the requirements of the ignition system of an internal combustion engine, it will be understood that the pulse producing means are not limited in their application to such systems, and have utility apart from such systems, and that other uses and applications of the inventions disclosed and modifications thereof will be obvious to those skilled in the art without departing from the spirit and the scope thereof.

The invention may be embodied in other specific forms without departing from the spirit of essential characteristics thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

What is claimed and desired to be secured by United States Letters Patent is:

1. In an internal combustion engine ignition system having a primary circuit, a high voltage secondary circuit inductively coupled to said primary circuit, and a plurality of spark plugs adapted to be energized by said secondary circuit, means for selectively energizing said spark plugs with voltage from said secondary circuit comprising a plurality of radiation sensitive elements individual to each of said spark plugs connected to said secondary circuit, a source of radiant energy, and means operative to effect sequential radiation of said elements from said source to sequentially render said elements conductive.

2. In an ignition system for an internal combustion engine, means for producing electrical pulses, a spark gap, a photoconductive cell connected in series circuit association with said pulse producing means source and with said spark gap, a source of radiant energy, and means controlling radiant energy from said source to said cell to render said cell alternately conducting and non-conducting, respectively.

3. In an ignition system for an internal combustion engine, means for producing high voltage electrical pulses, a spark plug, a photoconductive cell in series circuit relation between said spark plug and said source, and means to selectively illuminate said cell to conductively connect said spark plug with said source only during the period of a selected pulse.

4. An ignition system for an internal combustion engine, comprising means for producing pulses of high voltage, a plurality of spark plugs, a photoconductive cell inserted in series circuit relation between each spark plug and said source, and means to sequentially and intermittently illuminate said cells to conductively connect a selected spark pluk for the passing of a selected pulse thereto at a given instant, and to impede the passing of the selected pulse to the other spark plugs at that instant.

5. An electrical system comprising a source of electrical pulses, a load circuit, a photosensitive cell having a high resistance when dark and a low resistance when illuminated connected in series circuit relation between said load circuit to said source and normally prevent said pulse from being transmitted to said load circuit in non-conductive relation to said source, and means to selectively illuminate said cell to effect the conductive connection of said load circuit to said source for the passage of a selected pulse to said load circuit from said source.

6. In an ignition system for internal combustion engines, a first photoconductive cell, a first means to intermittently illuminate said first cell, a second photoconductive cell, a second means to intermittently illuminate said second cell in synchronism with the illuminating of

said first cell, means to produce pulses of high voltage connected in circuit association with said first cell and with said second cell and controllable by said first cell, and a spark plug connected to be energized by said pulse producing means through said second cell.

7. In an ignition system for internal combustion engines, a photoconductive cell, a source of direct current, an electron tube having a grid circuit, a capacitor in a control grid circuit of said electron tube, said capacitor being connected to said direct current source to be charged thereby and to said cell to be discharged when said cell is illuminated, means to cyclically illuminate and darken said cell, to thereby control discharge and charge of said capacitor, respectively, a spark gap in circuit association with said electron tube, and means responsive to current conduction in said tube to produce pulses of voltage at said gap.

8. In the ignition means of claim 7, said electron tube means comprising a gas discharge tube having a control grid, a cathode and an anode, a bias voltage battery connected to said control grid and to said cathode, a source of alternating current connected to said cathode and to said anode, a resistor connected to said control grid and to said cathode, and connected in the path of the charging and discharging current of said capacitor, respectively.

9. In an ignition system for an internal combustion engine, means for producing electrical pulses, a spark gap, a cadmium sulfide photoconductive cell connected in series circuit association with said means and with said spark gap through which said pulses are conducted, a source of radiant energy, and means controlling energy radiating from said source to said cell to render said cell alternately conducting and non-conducting respectively.

10. In an ignition system for an internal combustion engine, means for producing electrical pulses, a spark gap, a photoconductive cell formed of a binary compound connected in series circuit association between said means and said spark gap through which said pulses are conductive, a source of radiant energy, and means controlling radiant energy from said source to said cell to render said cell alternately conducting and non-conducting, respectively.

11. An ignition system for internal combustion engines, comprising a first photoconductive cell, a first means to alternately illuminate and darken said cell, respectively, a group of photoconductive cells including a second photoconductive cell, spark plugs connected to said cells, means to produce pulses of high voltage connected in circuit association with said first cell and with said group of cells, and controllable by said first cell, and means to alternately illuminate and darken said second cell, respectively, in synchronism with selected illumination of said first cell.

12. In an ignition system for an internal combustion engine, a beam power tetrode tube including a control grid, means normally biasing said control grid to render said tube substantially non-conducting, a spark coil having a primary winding and having a secondary winding, a spark plug connected to said secondary winding, a gas discharge tube connected normally maintaining current flow through said primary winding, pulse producing means operatively connected to said control grid to apply a pulse of voltage to said control grid to render said tetrode conducting, and means in circuit association with said tetrode tube and inductively coupled to means in circuit association with said gas discharge tube to render said gas discharge tube non-conducting when said tetrode tube becomes conducting and thereby interrupt current flow in said primary winding.

13. In an ignition system for an internal combustion engine, a first gas discharge tube having a control grid, a cathode and an anode, an initially charged capacitor, a transformer having a primary winding, said capacitor and said primary winding being connected in series and in a circuit connecting said anode with said cathode, a second gas discharge tube having a control grid, a cathode and an anode, means connecting said control grid and said cathode of said second tube to said charged capacitor to render said second tube non-conducting, pulse producing means connected to said control grid of said first tube to apply a pulse of voltage thereto and render said first tube conducting to thereby discharge said capacitor through said primary winding, a secondary winding on said transformer, a spark plug connected to said secondary winding, means operative upon the discharging of said capacitor to render said first tube non-conducting, a battery, and means operative upon the discharge of said capacitor to render said second tube conducting to thereby conductively connect said capacitor with said battery to restore the charge to said capacitor.

14. The ignition means of claim 13, with the addition of means in circuit association with said capacitor and with said control grid of said first tube and operative during the restoration of charge to said capacitor to provide a high negative bias to said control grid.

15. In the ignition means of claim 13, the provision of an inductance in series with said battery and operative to limit the initial flow of current to said capacitor when it is connected to said battery to restore its charge.

16. In the ignition means of claim 13, with said pulse producing means comprising a capacitor, a battery, and a photosensitive cell in circuit association and means to alternately render said cell conducting and non-conducting, respectively.

17. In an electrical circuit, a first electrical conductive channel, a plurality of electrically conductive channels distinct from said first channel, a like plurality of compound type radiation sensitive elements each connected to one of said plurality of channels and to said first channel, a source of radiant energy and means operative to effect stimulation of selected ones of said elements.

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