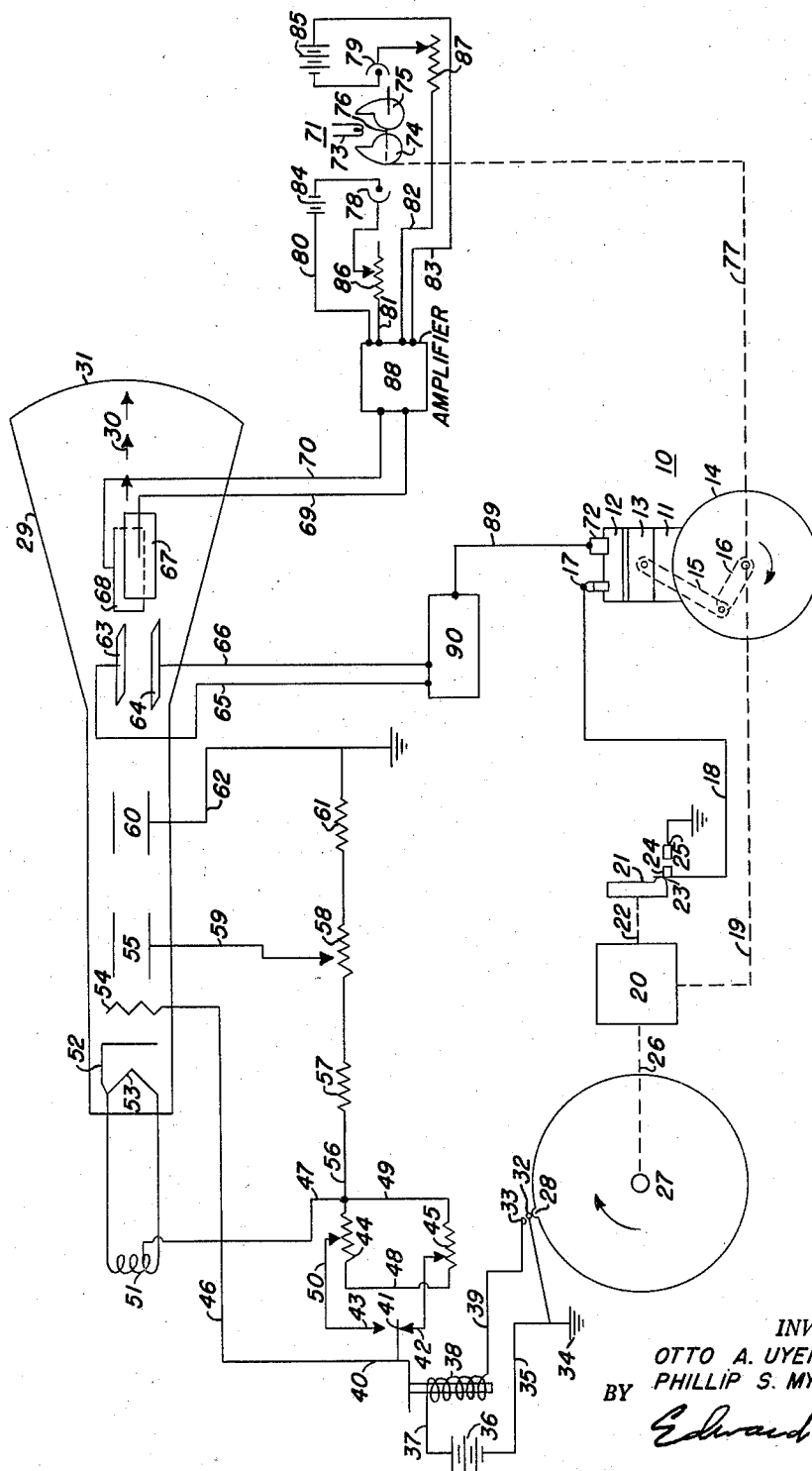


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WITHIN INTERNAL COMBUSTION ENGINES
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APPARATUS FOR DETECTING UNCONTROLLED COMBUSTION WITHIN INTERNAL COMBUSTION ENGINES

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The present invention relates to an apparatus for detecting autoignition within internal combustion engines and, more particularly, to means for interrupting the spark cycle in relation to the detecting cycle or cycles so that preignition before or after sparking can be detected, studied, and recorded.

Changes in design and increases in engine compression ratios have allowed the more efficient consumption of motor fuels in the modern internal combustion engines. However, during actual road operation of these engines there occurs an increased tendency for preignition within the combustion chamber with attendant high rates of pressure increase, knocking, severe wear, and corrosion of parts, and sometimes actual destruction of valves, pistons, and cylinder walls. This phenomenon of uncontrolled combustion is not new nor associated only with the high compression ratio engines but has been an inherent difficulty with the Otto cycle engine since its inception. The terms used to describe the various forms of uncontrolled combustion have been somewhat confused by writers on the subject and, accordingly, it is advisable to set forth at least in part the definitions intended to apply herein.

The combustion occurring within a combustion chamber may be spark induced or may be a combination of combustions caused by other sources of ignition. These latter combustions are termed broadly "uncontrolled combustion" since the time sequence of their occurrence is not directly within the control of the mechanical features of the engine. This uncontrolled combustion may be due to many conditions existing during the compression and firing cycle of the engine and is logically divided into (1) those conditions of temperature and pressure which causes ignition which is not a direct result of the spark and (2) those conditions other than temperature and pressure which cause a form of ignition not induced by spark. Within the meaning of this specification, uncontrolled ignition caused by conditions of temperature and pressure will be called "autoignition" and the balance of the conditions which cause uncontrolled ignition will be termed "hot spot ignition." Thus knock, which has been defined by others as the spontaneous ignition of a portion of the end gas as a result of its temperature and pressure, is included within the term "autoignition." That type of preignition (ignition occurring before spark) caused by hot surfaces, which is primarily associated with aircraft engines, is necessarily excluded from within the definition of "autoignition" and falls within the term "hot spot" ignition. Those conditions which cause "hot spot" ignition may include any external means (except spark) that fires off the charge of combustion mixture or portions thereof by catalytic action, glow phenomenon, hot surfaces, or pieces of loose flakes of deposit; or broadly, deposit-induced ignition. Preignition includes any hot spot ignition previous to spark. Those phenomena termed after-firing and after-running are included in hot spot ignition.

Prior investigators have used various means for study-

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ing uncontrolled ignition. For example, studies have been made in an L-head single cylinder engine wherein a number of ionization gaps are placed within the combustion chamber. These ionization gaps have two electrodes spaced several thousandths of an inch apart which detect the presence of ignited gases therebetween by the change in conductivity caused by the ionization present in the flame. The gap devices are connected to an electronic apparatus designed to establish the point of time in the engine cycle at which the combustion appeared at a given gap. In another apparatus, a single ionization gap is located some distance from the spark plug at a point near the center of the area above the piston for the purpose of giving a reliable indication of the degree of deposit-induced ignition at some time interval after spark ignition. The voltage change across a resistor due to the change in conductivity of the gap on arrival of the flame is transmitted through a cathode follower to a gating device, amplifier, and pulse generator to a recorder or electromechanical counter.

Under certain conditions, namely, that the flame from the hot spot ignition reach the ionization gap before the flame from the spark-induced ignition, detection of deposit-induced ignition, occurring after spark, is possible. The purpose of the gating device or circuit is to permit only the deposit-induced flames to actuate the counter or recorder by rendering the recorder non-operative, previous to the arrival of the flame front from the spark-induced ignition. However, even with the gating device or circuit, uncertainties in the count of deposit-induced flames is introduced because of cycle-to-cycle variations in the speed of travel in the spark-induced flame and accurate and reliable detection can be accomplished only previous to the occurrence of spark. In addition, loose deposit flakes or particles might bridge the ionization gap and cause spurious counts. Phenomena associated with pre-flame reactions might change the conductivity of the gap, thereby causing the counter to record a deposit-induced ignition even though none occurred.

Other investigators have used ionization gaps to detect preignition due to combustion chamber deposits in combination with a rate of change of pressure pick-up, the signal from which is observed on an oscilloscope screen. The instrument detects only that preignition which occurs before spark and the detector circuit is cut off actually a few degrees before spark. The principal disadvantage to these prior devices is that they require many hours of engine operation and require that preignition occurs before spark.

In accordance with the present invention, a device and method is provided to detect uncontrolled ignition caused by hot spots or other conditions in the combustion chamber besides normal spark, including preignition, without the disadvantages of previous devices.

More particularly, the present invention comprises a design of switch arrangements and associated circuits which periodically interrupts the spark for a single cycle or cycles and also provides a means for detecting whether or not combustion occurred during this non-sparking cycle or cycles. If combustion occurs during this non-sparking cycle or cycles it is clearly the result of uncontrolled combustion.

Accordingly, a primary object of the invention is to provide a method and apparatus for detecting and recording uncontrolled ignition within the combustion chamber of an internal combustion engine.

A second object of the invention is to provide an instrument to detect any combustion other than an intentionally fired and desired combustion during either an unfired or fired cycle.

Other objects and advantages of the invention will in part be obvious and in part appear hereinafter.

In the drawing, one embodiment of the invention is shown diagrammatically.

The description of the apparatus and tracing of associated circuits may be as follows, referring to the drawing wherein single cylinder, 2 or 4 cycle engine 10 has cylinder 11 and combustion chamber 12. Piston 13 operates within cylinder 11 rotating fly wheel 14 through connecting rod 15 and crankshaft 16. Spark plug 17 is supplied current through line 18 from a suitable voltage source (not shown). A spark grounding or interrupting switch arrangement is shown comprising drive connection 19 connected to reduction gear 20, which rotates disc 21 through drive connection 22. Disc 21 has raised portion 23 which intermittently raises contact 24 of wire 18 against grounded contact 25, during the rotation of disc 21. Reduction gear 20 has drive connection 26 leading to rotating disc 27 having raised portion 28. Cathode ray oscilloscope tube 29 of the electrostatic deflection type connected to a suitable power supply (not shown) is altered by a circuit adapted to brighten the cathode ray 30 impinging on fluorescent screen 31. At desired periodic intervals, to be described subsequently, regulated either manually or by reduction gear 20 and the resultant speed of rotation of disc 27, the raised portion 28 closes contact 32 against contact 33. This completes the circuit consisting of a battery 36, wire 37, relay 38, wire 39, contact points 32 and 33, wire 35, and actuates the relay 38. The closing of contacts 32 and 33 is regulated to occur simultaneously with the spark interruption by contacts 24 and 25 as will be described. Relay 38 serves as a double throw switch 40 making and breaking the connection between movable contact 41 and fixed contacts 42 and 43. The movable contacts of potentiometers 44 and 45 are connected to the intensity grid of the cathode ray tube via the contact points of relay 38 and wire 46. Wire 48 is connected to the negative voltage of the oscilloscope power supply (not shown). The cathode ray oscilloscope has the usual form of electron emitting cathode 52, heater 53 (which is heated by transformer 51), and control grid 54. The focusing is accomplished by the second anode 60 and by the first focusing anode 55 which is supplied with the proper voltage through wire 56, resistance 57, potentiometer 58, and wire 59. The deflection area of the cathode ray tube 29 is represented by deflection plates 63 and 64 with connecting wires 65 and 66 and deflecting plates 67 and 68 with connecting wires 69 and 70.

It is seen that closing of contacts 32 and 33 actuates relay 38, closing contacts 41 and 42 which increases the flow of electrons from cathode 52 through grid 54.

In order that the screen 31 function to depict the piston position in relation to time and the pressure or rate of change of pressure with time, represented by the function

$$\frac{dp}{dt}$$

where p equals pressure and t equals time, the motion of the cathode ray in one direction is influenced by a signal from sweep circuit 71 and the motion in the other direction is influenced by pick-up 72. Since the embodiments shown for these two respective means are the preferred species thereof and other means may be used for the same purposes, their functions will be described separately.

The sweep circuit 71 comprises light source 73 positioned between two cam-shaped opaque shields 74 and 75 which are rotated on shaft 76 through drive connection 77 extending from the camshaft (or crankshaft, if preferred). Two matched photoelectric tubes 78 and 79 are spaced from the shields 74 and 75 in such a manner that as the shaft 76 rotates the shields together their cam surfaces periodically varies the light from the light source 73 to the photoelectric tubes and as rotation continues the

curved edge of the cams gradually allows the light to impinge with an increasing amount on one tube and with a decreasing amount on the other tube. Under the influence of the light source, the photo tubes send a signal through their respective circuits, indicated by wires 80 and 81, and 82 and 83 with associated batteries 84 and 85 and variable resistors 86 and 87 to amplifier 88 wherein the signal is amplified to a sufficient voltage which is impressed across deflecting plates 67 and 68. This controls the magnitude of the sweep of the cathode ray 30 on screen 31 as a function of the piston (13) position within cylinder 11. This is represented as the cycle between "bottom center," "top center," and back to "bottom center" during the compression and firing stroke if the drive 77 is connected to the crankshaft of the engine. To obtain this relationship, the rotation of drive connection 77 and shaft 76 is adjusted so that as the piston passes upwardly in the beginning of the compression stroke, one cam is just beginning to allow a small amount of light to impinge on one of the phototubes and the other cam is just beginning to decrease from the maximum amount of the light falling in the other phototube. This light change caused by the rotation of the cams produces voltages that gradually sweep the cathode ray 30 across the screen 31 and almost instantaneously returns it to the starting position for the next cycle. A suitable sweep circuit device for this purpose of influencing plates 67 and 68 comprises the Rowe Radio Research Laboratory Co.'s Angular Sweep Potentiometer, type AP2XB and type AP2.

In place of the sweep circuit 71 an oscillator adapted to give a saw-tooth voltage curve in relation to time may be used and its voltage signal may be impressed across the plates 67 and 68. Such an oscillator is built into many oscillographs and could be synchronized with the engine rotation either by internal synchronization which is customarily provided in the oscillograph or by an external synchronization signal provided cyclically from the engine.

A further expedient for impressing a voltage signal across plates 67 and 68 is by means of a potentiometer having a sweep contact rotated by the engine revolution which picks up and transmits a varying voltage to the plates influencing the movement of the cathode ray 30.

The movement of the cathode ray 30 perpendicular to the previously described sweep movement on screen 31 is proportional to the pressure directly or to the rate of change of pressure in relationship to time,

$$\left(\frac{dp}{dt}\right)$$

and is accomplished by placing a voltage signal across plates 63 and 64 through pick-up 72. This is accomplished by pick-up device 72 which generates a voltage proportional to

$$\frac{dp}{dt}$$

One such instrument is manufactured by the Phillips Petroleum Company and is used for other purposes such as fuel rating. This voltage passes through wire 89 to amplifier 90 and thence to the pair of deflection plates 63 and 64 via wires 65 and 66. Thus the movement of the cathode ray 30 along one axis is a function of

$$\frac{dp}{dt}$$

and the movement along the other axis is a function of piston position.

In place of the rate-of-change-of-pressure pick-up, a pick-up that is directly responsive to pressure may be employed to detect if hot spot ignition occurred. For this purpose, the Li pick-up as manufactured by Control Engineering Corporation is suitable. This pressure pick-up comprises essentially a flexible diaphragm direct-

ly under influence of pressure within the combustion zone. The diaphragm is associated with and impinges upon a small cylinder in direct contact with the diaphragm. The cylinder is tightly wrapped with strained gage wire in the form of two separate coils, one coiled around the circumference of the cylinder and the other coiled in loops, the planes of which lie against the first coil and parallel with the axis of the cylinder. Under influence of pressure the cylinder is compressed slightly and as a consequence its cross-sectional area increases. This expansion causes a change in the cross-sectional area of the respective coils and, as a result, the amount of current flowing therethrough per unit of time also changes. This change is picked up by an appropriate circuit (not shown) and sent to the plates 63 and 64.

A third means for changing the path of cathode ray 30 when combustion occurs within the combustion zone 12 comprises a quartz window set within the cylinder wall 11 with an associated flame radiation detector such as a photoelectric cell. Such an arrangement would give an indication or signal proportional to the change in relative illumination occurring within the combustion zone. In using such devices, however, adjustment should be made so that illumination due to "cool flame combustion" is eliminated.

In operation, the reduction gear 20 and drive connections 26, 22, and 77 are adjusted so that at the moment piston 13 is at the bottom center position and about to begin the upward compression stroke, disc 27 closes contacts 32 and 33 to brighten the scope, rotating disc 21 closes contacts 24 and 25 to ground out the spark, and sweep circuit 71 causes the spot or cathode ray 30 to travel across the face of screen 31. If desired, the picture produced on the screen may be photographed through the use of a camera focused thereon, the shutter of which is either operated manually or opened and closed by the completion of the cycle as through a mechanism (not shown) connected to reduction gear 20. In place of or in conjunction with photographing the results, it is often desirable to employ a counter, again connected through the reduction gear, to count only the number of uncontrolled combustions occurring in non-fired cycles or times of interrupted spark. Also, it is expedient to use two counters, one to record the number of spark interruptions and a second to record the number of times the spark was interrupted but combustion occurred. For this purpose, a Veeder-Root counter manufactured by Veeder-Root Inc., Hartford, Connecticut, was used, but other types are suitable.

A typical example of the operation of the device and the results obtained thereby follow:

The amplifiers, heaters, etc., were turned on for about 15 minutes to bring the detecting devices to operating stability. An L-head CFR engine was brought to operating temperature, including a 105° F. inlet mixture temperature, a coolant temperature of 212° F., etc. The fuel under investigation was carbureted and admitted to the combustion chamber. As the engine operated, the spark was interrupted by the described apparatus every 56 engine revolutions, and the resultant oscillographs were observed and photographed on a single frame for 25 non-fired cycles in cases with relatively few hot spot ignitions, and on a double frame for 12 and 13 non-fired cycles where hot spot ignition was frequent. The developed films were then analyzed on an arbitrary basis of the number of hot spot ignitions per 100 non-fired cycles in order to compare and evaluate the fuel. The method is useful not only for evaluating various fuels and mixtures thereof, but also for evaluating the effects of oils and fuel or oil additives upon fuel combustion.

The invention, accordingly, comprises apparatus for detecting uncontrolled ignition or combustion within the combustion chamber of an internal combustion engine. Either a 2-cycle or 4-cycle engine may be used and the engine may have any number of cylinders. Single cylin-

der L-head CFR engines are especially adapted to making these tests. The engine is ordinarily operated under conditions whereby studies may be made either under load, that is with the engine driving a generator or other suitable power-consuming device or under idling conditions, i. e., no load. Particular features of the apparatus include the means for grounding out the sparking device and means for brightening the oscilloscope during the detection steps. The features of the method include the step of grounding out the spark so that uncontrolled ignition can be detected during the entire compression and what would normally be the fired cycle. The method also includes the step of brightening the scope during the detection of piston position and detecting a change in a physical property within the combustion chamber simultaneously therewith.

Also, with the method and apparatus of this invention, a new combustion phenomenon has been detected which produces on the oscilloscope screen a sharp peak in opposite direction to and immediately preceding, or within the area of, the usual dip observed on the screen when an uncontrolled combustion occurs. The ordinary dip represents a voltage drop arising from passage of current from a battery and a resistor by virtue of ions in the flame front. The new phenomenon observed therefore appears to be an actual voltage generation across the gap, and is believed to indicate a type of hot spot ignition which occurs only when said hot spot ignition is severe enough to be, or go into, pre-ignition. If the battery is reversed in polarity, the aforementioned peak is no longer evident because the polarity of the voltage, apparently generated in the gap, is in the same direction. Furthermore, if the battery is removed and the battery terminal is grounded, the peak appears as before but the usual dip is, of course, missing. These observations show the consistency of the new phenomenon, which is considered to be of fundamental significance, and the discovery of the same was made possible by the invention described herein.

The change in physical property detected within the combustion chamber in accordance with this invention includes rate of change of pressure with time, pressure per se, ionization, light radiation, temperature, sound waves, vibration, or combinations of two or more of these physical changes. Ionization is detected by means of an ionization gap device located within the combustion chamber wherein the appearance of the flame between spaced electrodes allows the passage of current therebetween in proportion to the flame intensity or degree and kind of ionization. For this purpose, a spark plug or other insulated gap suitable for detecting ionization in series with a battery or power supply and a resistor is used. Light radiation is detected by means of a quartz window in the cylinder wall or head adjacent the combustion chamber through which a photocell detects the appearance of flame therein and transmits a signal to the oscilloscope. Temperature is detected by means of one or more sensitive thermocouples located within the combustion chamber. Sound waves may be detected by means of an acoustical device similar to a microphone or stethoscope affixed or located near the combustion chamber whereby the sound received may be detected orally or converted to voltage and observed on the screen or counted by a counter. Vibration may be detected by a vibration pick-up such as is made by the Sperry Company and used in engine knock indicators. In this case the pick-up must be attached to the engine cylinder.

The preferred physical property detected within the combustion chamber is rate of change of pressure because it provides the greatest differential indications between hot spot combustion and normal dead cycle operation. Where two or more physical changes are measured it is preferred that rate of change of pressure and ionization be used in combination, or pressure change and light radiation, since one may supplement the other. In mak-

ing such combination measurements, it is advantageous to make the determinations using one physical property and then check the results by repeating the experiments using another physical property. In this way the course of the complicated reactions and phenomena occurring in the combustion chamber may be more completely investigated.

Although the invention has been described using specific embodiments, the only limitations thereon appear in the appended claims.

What is claimed is:

1. An instrument to detect uncontrolled combustion with the combustion chamber of an internal combustion engine equipped with a sparking device comprising in combination, means for detecting a change in a physical property within said combustion chamber in relation to piston position during a compression and combustion cycle, means including an oscillograph to depict said change in physical property graphically on a screen, an ignition grounding device connected to a rotating part of said engine through a reduction gear whereby at predetermined intervals the ignition impulse to the sparking device is grounded out so that a comparison of fired and unfired cycles may be made.

2. An instrument to detect uncontrolled combustion within the combustion chamber of an internal combustion engine equipped with a sparking device comprising, in combination, means for detecting a change in a physical property within said combustion chamber in relation to piston position during a compression and combustion cycle, means including an oscillograph to depict said change in physical property graphically on a screen, an ignition grounding device comprising a rotatable disc connected to a rotating part of said engine through a reduction gear, said disc having a raised portion on its peripheral surface, a spring-loaded member in contact with the peripheral surface of said disc and connected between said sparking device and the electrical system of said engine, a grounded contact spaced from said spring-loaded member whereby said raised portion periodically moves said spring-loaded member against said grounded contact and shorts out the ignition of said sparking device.

3. An instrument to detect uncontrolled combustion within the combustion chamber of an internal combustion engine equipped with a sparking device comprising, in combination, means for detecting a change in a physical property within said combustion chamber in relation to piston position during a compression and combustion cycle, means including an oscillograph to depict and trace said change in physical property graphically on a screen, an ignition grounding device connected to a rotating part of said engine through a reduction gear, and means for simultaneously brightening said trace during the period of detecting said change in physical property at the time said ignition grounding device is actuated, whereby a comparison of fired and non-fired cycles within said combustion chamber may be made.

4. An instrument to detect uncontrolled combustion within the combustion chamber of an internal combustion engine equipped with an electrical system and a sparking device comprising, in combination, means for detecting a change in a physical property within said combustion chamber in relation to piston position dur-

ing a compression and combustion cycle, means including an oscillograph to depict said change in physical property graphically on a screen, a power supply for said oscillograph, an ignition grounding device comprising a rotatable disc connected to a rotating part of said engine through a reduction gear, said disc having a raised portion on its circumference, a spring-loaded member in contact with the circumferential surface of said disc and connected between said sparking device and the electrical system of said engine, a grounded contact spaced from said spring-loaded member whereby rotation of said disc causes said raised portion to periodically raise said spring-loaded member against said grounded contact to short out the ignition of said sparking device, means for simultaneously brightening said oscillograph screen including a second rotating disc connected to said reduction gear, said second disc having a raised portion on its peripheral surface, a spring-loaded member in contact with the peripheral surface of said second disc and connected in series with a source of electrical current and a relay switch to a stationary contact whereby said raised portion periodically moves said spring-loaded member against said stationary contact to actuate said relay, said relay having two terminals, said terminals being connected through variable resistances to said power source and to the cathode and control grid of said oscillograph whereby simultaneously with the grounding of said sparking device said second rotating disc causes said relay switch connect said cathode and control grid to a terminal of increased electrical power and brighten graphic indicia on said screen.

5. An instrument in accordance with claim 3 in which the means for brightening said oscilloscope trace include a rotating disc having a raised portion on its circumferential edge, a flexible conduit member in contact with said circumferential edge, said conduit being connected at its other end through a source of electrical energy to a relay type switch to a second spaced contact whereby said raised portion contacts said flexible conduit to raise same against said second contact or third contact operated by said relay, said third contact opening and closing the power supply circuit to said oscilloscope to brighten said trace.

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