

Oct. 2, 1962

J. E. LINDBERG, JR., ETAL

3,056,918

ENGINE ANALYZER EMPLOYING CATHODE-RAY TUBE

Original Filed Oct. 14, 1955

6 Sheets-Sheet 1

Fig. 1.

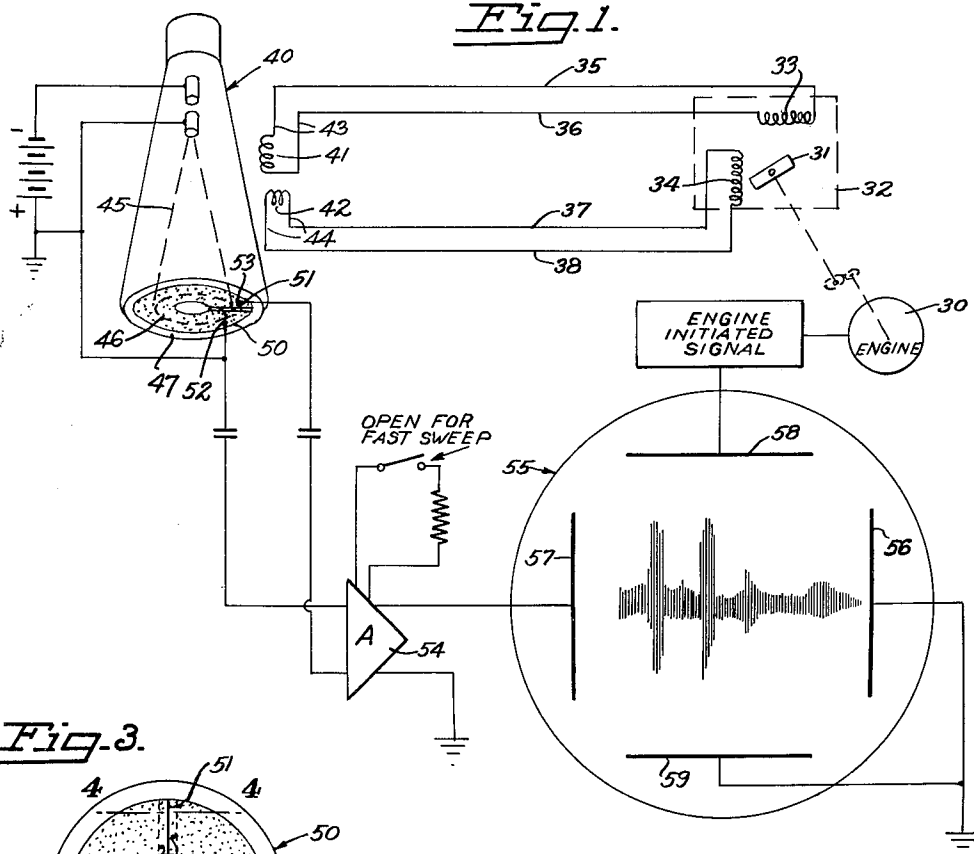


Fig. 3.

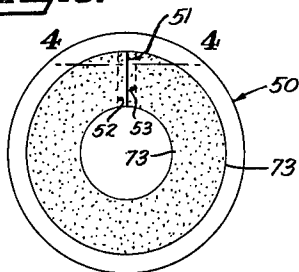


Fig. 6.

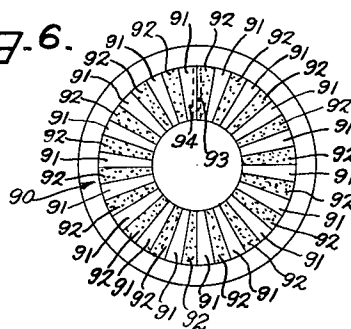


Fig. 5.

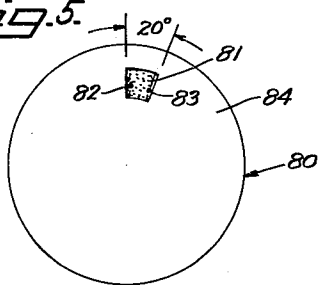
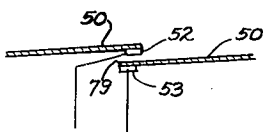


Fig. 4.



INVENTORS
JOHN E. LINDBERG, JR.
LESLIE J. COOK.
BY *A. D. Doherty*
ATTORNEY

Oct. 2, 1962

J. E. LINDBERG, JR., ETAL

3,056,918

ENGINE ANALYZER EMPLOYING CATHODE-RAY TUBE

Original Filed Oct. 14, 1955

6 Sheets-Sheet 2

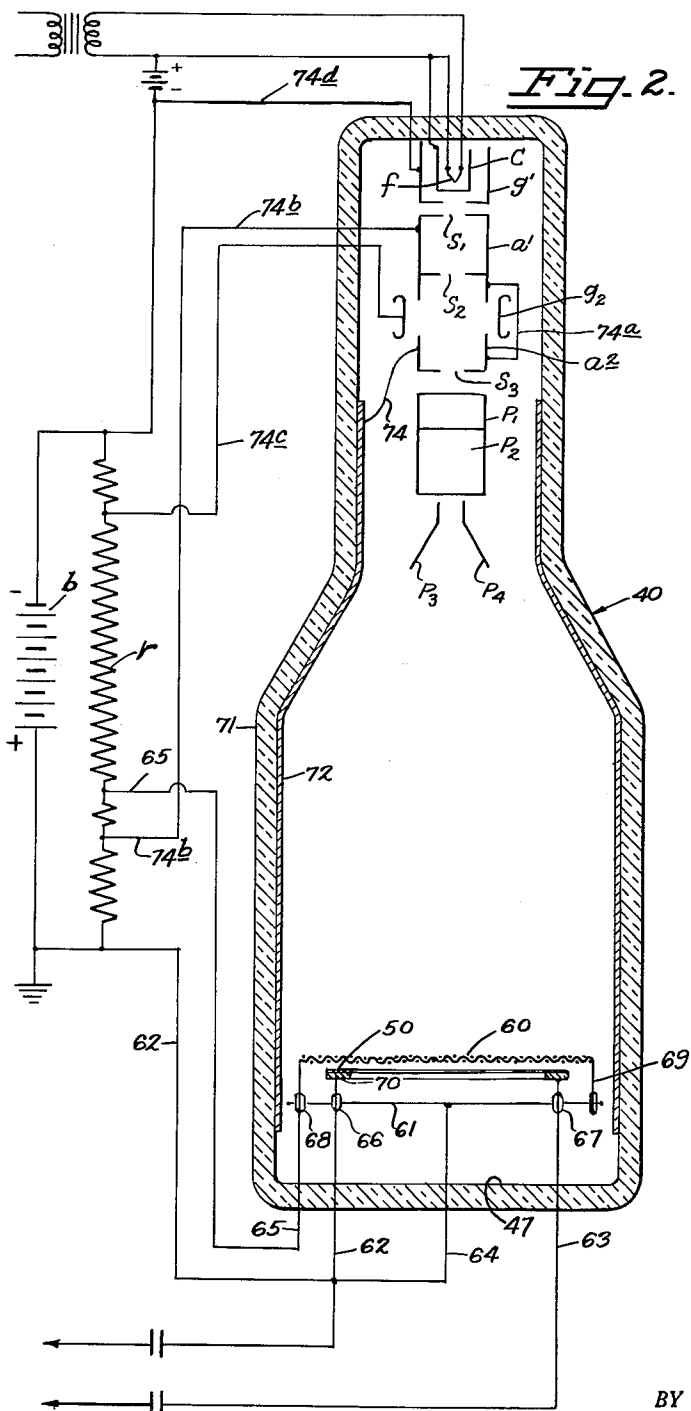


Fig. 8.

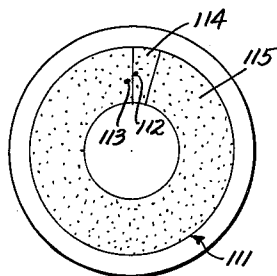


Fig. 9.

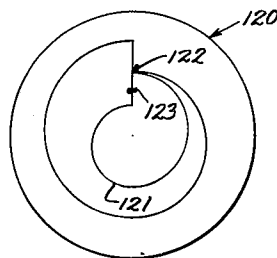
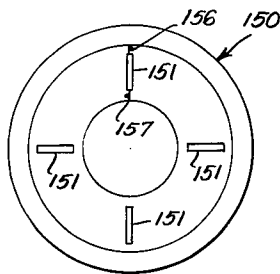


Fig. 17.



INVENTORS
JOHN E. LINDBERG, JR.
LESLIE J. COOK
BY *Admham Owen*
ATTORNEY

Oct. 2, 1962

J. E. LINDBERG, JR., ETAL

3,056,918

ENGINE ANALYZER EMPLOYING CATHODE-RAY TUBE

Original Filed Oct. 14, 1955

6 Sheets-Sheet 3

Fig. 10.

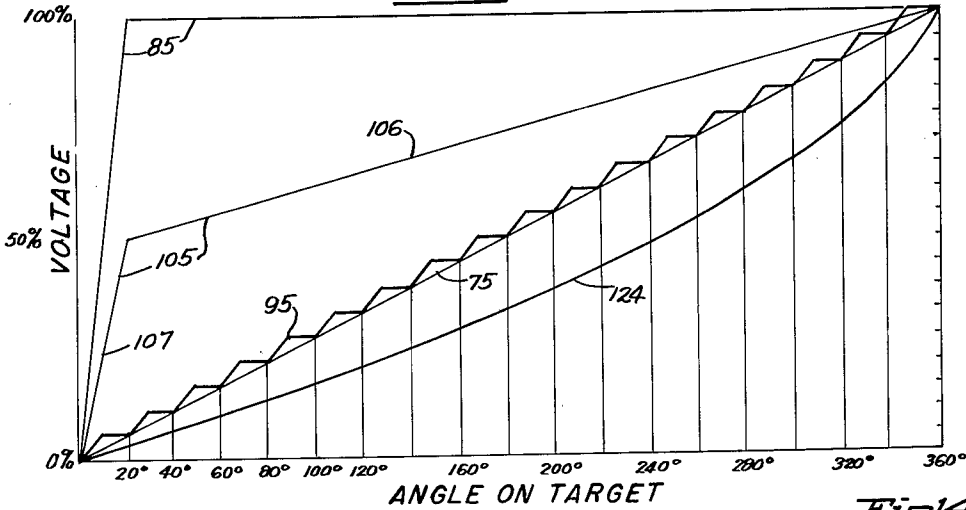


Fig. 7.

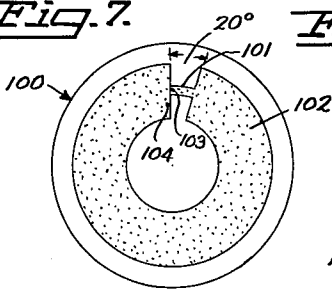


Fig. 16.

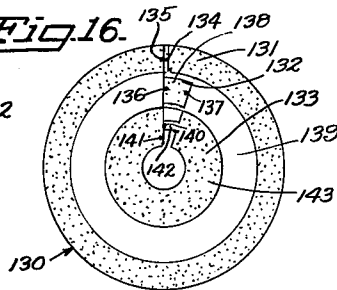


Fig. 14.

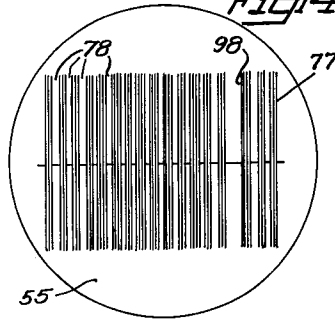


Fig. 11.

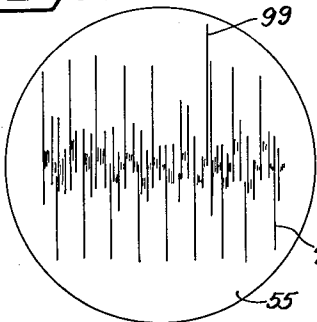


Fig. 12.

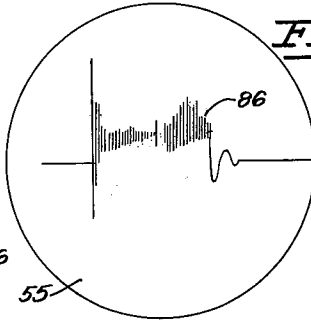


Fig. 15.

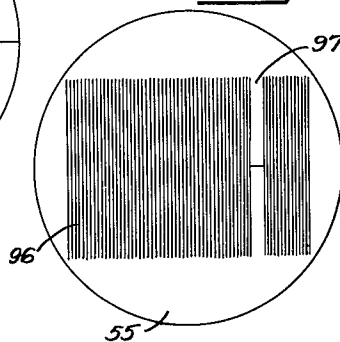
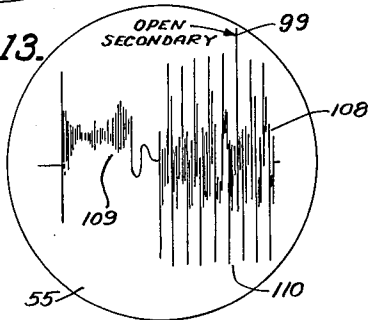


Fig. 13.



INVENTORS
JOHN E. LINDBERG, JR.
LESLIE J. COOK
BY

Adm. Law
ATTORNEY

Oct. 2, 1962

J. E. LINDBERG, JR., ETAL

3,056,918

ENGINE ANALYZER EMPLOYING CATHODE-RAY TUBE

Original Filed Oct. 14, 1955

6 Sheets-Sheet 4

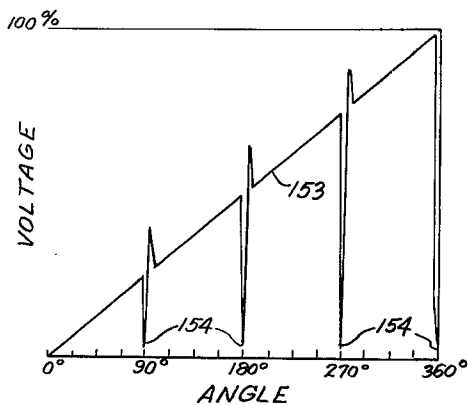
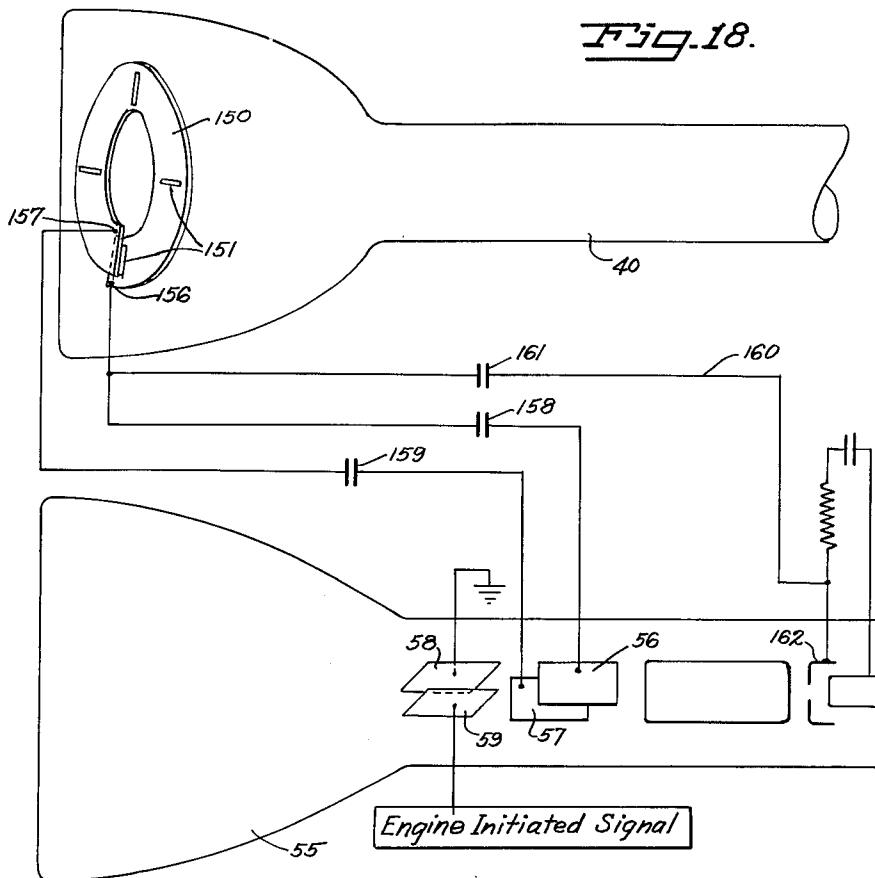
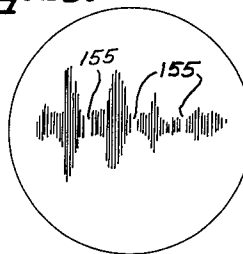


Fig. 19.

Fig. 20.



INVENTORS
JOHN E. LINDBERG, JR.
LESLIE J. COOK
BY
P. D. M. Owen
ATTORNEY

Oct. 2, 1962

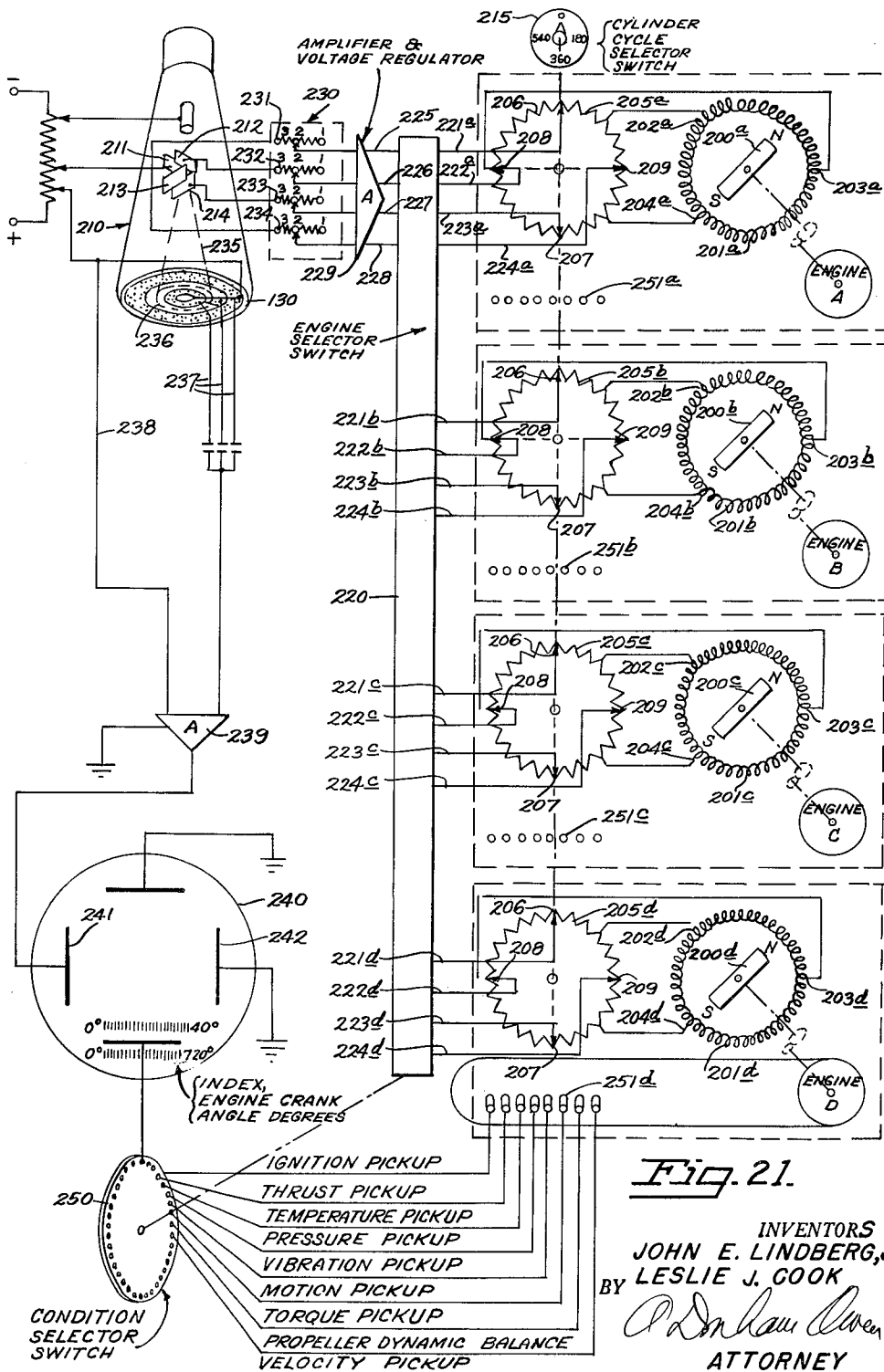
J. E. LINDBERG, JR., ETAL

3,056,918

ENGINE ANALYZER EMPLOYING CATHODE-RAY TUBE

Original Filed Oct. 14, 1955

6 Sheets-Sheet 5



Oct. 2, 1962

J. E. LINDBERG, JR., ETAL

3,056,918

ENGINE ANALYZER EMPLOYING CATHODE-RAY TUBE

Original Filed Oct. 14, 1955

6 Sheets-Sheet 6

Fig. 22.

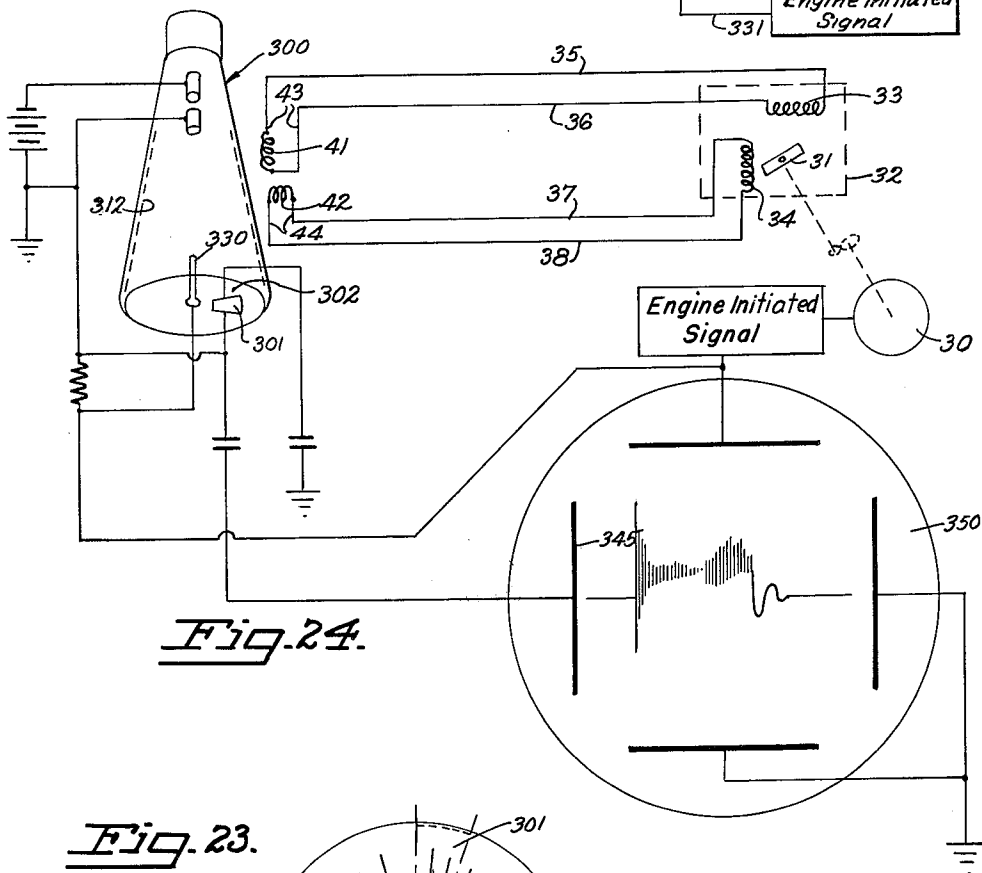
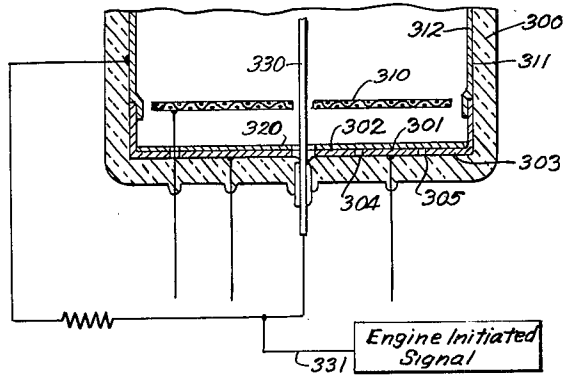
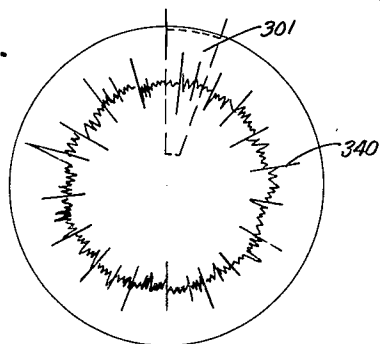


Fig. 24.

Fig. 23.



INVENTORS
JOHN E. LINDBERG, JR.
LESLIE J. COOK
BY *A. D. Ham Allen*
ATTORNEY.

1

3,056,918

ENGINE ANALYZER EMPLOYING CATHODE-RAY TUBE

John E. Lindberg, Jr., and Leslie J. Cook, Lafayette, Calif.; said Cook assignor to said Lindberg
Original application Oct. 14, 1955, Ser. No. 540,462. Divided and this application Apr. 16, 1959, Ser. No. 810,520

16 Claims. (Cl. 324—16)

This invention relates to an improved engine analyzer and more particularly relates to a positively synchronized sweep circuit for an engine analyzer utilizing an auxiliary cathode-ray tube having a resistance-ring target. This application is a division of Serial No. 540,462, filed October 14, 1955, now abandoned.

Engine analyzers, such as the one illustrated in the John E. Lindberg, Jr. Patent 2,518,427, are used to investigate the performance of engines while they are in actual operation. Selected signals from any of various parts of the engine may be impressed across one set of deflection plates in a cathode ray oscilloscope, and a sweep signal is impressed across the other set of deflection plates. The result is a pattern that, when studied, indicates the performance of the engine.

Synchronization of the sweep circuit with the engine signal circuit has been a very difficult problem. Heretofore, sweep circuits have been initiated independently of the engine by charging and discharging a condenser or by some other means that varies the voltage at a uniform rate over a predetermined period of time, so as to change the voltage differential between the cathode ray deflection plates uniformly with time. But this type of sweep circuit has been unable to cope successfully with the synchronization problem, because an engine necessarily operates at different speeds, which vary tremendously. Whenever the engine speed changed, the sweep circuit tended to lengthen or shorten the diagram, and measurement of absolute lengths along the diagram became meaningless, since the lengths could not be related directly to engine conditions.

The prior art sought to solve this problem by providing, in various ways, compensation from an engine-initiated pulse. A typical compensator is shown in the E. F. Weller, Jr. et al. Patent No. 2,645,715. There, the charging rate of the sweep-generating condenser is regulated by a circuit which is controlled by pulses from the engine, to provide a constant amplitude sweep circuit. In other words, the independent sweep circuit was modified in the attempt to synchronize the voltage change with the engine speed. The modifying circuit for this compensating apparatus was very complex; the one referred to in E. F. Weller, Jr., et al., Patent 2,645,715 utilized six electronic tubes plus a mechanical circuit breaker. The best circuit currently in use is even more complex, and includes eleven electronic tubes. This reliance on compensators has left synchronization a difficult and expensive problem; special items of equipment, such as special generators, have been required; and the results have still not been completely satisfactory, especially during periods of acceleration and deceleration of the engine being studied.

We have solved these problems by a new approach to the sweep circuit. Our invention obtains its sweep circuit synchronization directly from the engine being analyzed. Our new sweep is always necessarily in phase with the engine signal, and synchronization of the sweep with the engine cycle is completely unaffected by changes in speed.

In addition to achieving the object of perfect synchronization, our sweep circuit has other remarkable features; it uses a standard generator which may already be on the engine, and contains no other moving parts. It makes it possible to time the initiation of the sweep di-

2

rectly in the cabin of the plane instead of having to make adjustments in the engine. In addition, as will appear, the engine provides a sweep circuit of great versatility; the type of sweep can be varied for different kinds of analysis simply by throwing a switch which changes circuit impedance.

In brief, our invention contemplates obtaining the basic sweep signal from a generator driven by the engine and running at engine cycle speed. In a typical example, two currents ninety degrees out of phase are obtained from the single generator, and these are impressed upon the two pairs of deflection plates of an auxiliary cathode ray tube so as to give a circular sweep. This signal—an electron beam moving in a circle—impinges on an annular resistance element, and thereby produces a sawtooth (or other type) of voltage which, properly amplified if necessary, can then be impressed across the sweep plates of the cathode ray tube of the engine analyzer itself. Basically, then, the invention operates by first using an engine to generate a circular sweep of electrons whose cycle therefore depends directly on the engine cycle; this circular-moving electron beam is then in combination with the annular resistance element to produce a varying electric voltage suitable for control of the engine analyzer sweep circuit.

Investigation revealed that prior-art cathode-ray tubes of this type were not satisfactory for engine analyzers because of distortions due to secondary electron emission and other factors; so another object of the invention is to provide a novel tube of this type that is satisfactory. This involves control of secondary emission and other problems.

Other features, objects, and advantages of the invention will become apparent from the following description presented in accordance with 35 U.S.C. 112.

In the drawings:

FIG. 1 is a diagrammatic representation of an apparatus and simple circuit embodying the principles of our invention. Hence magnetic deflection coils are used in place of electrostatic deflection plates, though either type of deflection system may be used.

FIG. 2 is a diagrammatic view in side elevation and in section of a cathode-ray tube having an annular resistance element and suitable for use in the present invention, shown also with some of its connected wiring. The wiring of the deflection plates has, however, been omitted from this view to avoid confusion; the deflection plates shown here are of the electrostatic type and may be connected as shown in FIG. 21.

FIG. 3 is a view in elevation of one form of annular resistance element suitable for use in our invention, wherein the resistance band is of constant width, so that its conductance varies uniformly with angular position around a full 360° cycle.

FIG. 4 is a view in section taken along the line 4—4 of FIG. 3, showing how the resistance element may be provided to give a continuous response for 360°.

FIG. 5 is a view similar to FIG. 3 of another type of resistance element also useful with our invention, wherein the element is segmental, so that the conductance varies uniformly with angular position over a small angle and then becomes zero and remains unchanged over the remainder of the cycle.

FIG. 6 is a view similar to FIG. 3 of another type of annular resistance element composed of many alternate elements, some having substantial resistance and separated by conductive segments.

FIG. 7 is a view similar to FIG. 3 of another type of annular resistance element wherein there are two segments, one of which is relatively short and varies uniformly over its arc between full resistance down to fifty percent resistance, while the other, much longer, segment

varies uniformly over its arc from fifty percent down to zero resistance.

FIG. 8 is a view similar to FIG. 7 showing a resistance element of a different structure, adapted to accomplish the same results.

FIG. 9 is a view showing a resistance element whose width varies constantly to produce a non-linear change in resistance.

FIG. 10 is a diagram, plotting angle against percent conductance for each of resistance elements shown in FIGS. 3 and 5 to 9, and corresponding to the final sweep curve for each element.

FIG. 11 is an illustration of one type of engine analyzer pattern, obtained from a signal initiated by the engine and from the sweep given by the element of FIG. 3.

FIG. 12 is an illustration of a pattern obtained from the same engine signal as that of FIG. 11 but using the sweep given by the element of FIG. 5.

FIG. 13 is an illustration of a pattern obtained from the same engine signal as FIGS. 11 and 12, using the element of FIG. 7 to obtain the sweep.

FIG. 14 is an illustration of another type of pattern, obtained from a different engine signal, using the sweep given by the element of FIG. 3.

FIG. 15 is an illustration of a pattern obtained from the same signal as that of FIG. 14 but using the sweep given by the element of FIG. 6.

FIG. 16 is a view similar to FIG. 2 showing a three-band combination resistance target, having annular bands at different radii to correspond to the elements shown in FIGS. 3, 5, and 7.

FIG. 17 is a view similar to FIG. 3 showing a resistance element that is indexed as to angular position.

FIG. 18 is a simplified circuit diagram showing how the element of FIG. 17 is used.

FIG. 19 is a diagram similar to FIG. 10 on a reduced scale, showing the curve produced by the indexed element of FIG. 17 in the circuit of FIG. 18.

FIG. 20 is an illustration of a pattern like that of FIG. 10, but using the indexed element of FIG. 17 and the circuit of FIG. 18.

FIG. 21 is a diagrammatic view showing a more complex apparatus and circuit than FIG. 1, but also embodying the principles of our invention.

FIG. 22 is a fragmentary view of the target portion of a modified type of cathode-ray tube that is generally like that of FIG. 2, but with differences in the target area, including a central electrode that can be connected to the engine-initiated signal.

FIG. 23 is a view in elevation showing a target of the type shown in FIG. 22, with an engine ignition pattern visible thereon.

FIG. 24 is a simplified circuit diagram of an analyzer utilizing the tube of FIG. 22.

(1) Simple Analyzer Using the Present Invention (Fig. 1)

While some of the applications of our invention involve complex circuits and apparatus, many of the basic principles are illustrated in the simple analyzer shown in FIG. 1, and the more complex applications will be better understood after considering this simple and practical embodiment.

(a) *A simple circular sweep.*—There are many ways of obtaining a circular sweep, some of which are shown in the drawings, and one of the simplest is shown in FIG. 1. An engine 30 to be analyzed drives a rotatable magnet 31 in a two-phase generator 32 at engine cycle speed, which, in an airplane engine, is one-half the crankshaft speed. The two-phase generator 32 has two stationary coils 33 and 34 located ninety degrees out of phase. Lead wires 35 and 36 extend from the coil 33 to a cathode-ray tube 40 (for some applications it may be desirable to include a transformer or an amplifier in these leads) and place a varying (sine wave) potential across one magnetic deflection coil 41. Similarly, lead wires 37, 38 from the

coil 34 place a varying (sine wave) potential, 90° out of phase with the prior signal, across another magnetic deflection coil 42, perpendicular to the coil 41. This affects an electron beam 45 causing it to move in a circular path 46 once per engine cycle. Flexible leads 43, 44, or slip rings, may be used to connect the coils 41, 42, to their leads 35, 36, 37, 38, so that the point of initiation of the circular sweep may be adjusted relative to the engine generator 32. This method of obtaining a circular sweep is well-known in the art. Other methods may also be used, including those shown in the co-pending application by John E. Lindberg, Jr., serial number 517,577, filed June 23, 1955.

(b) *The resistance ring 50 and associated parts.*—As the beam 45 moves in a circle, it impinges on an annular target, plate, or resistance ring 50, which may comprise a thin coating of semi-conductive material deposited on the inside glass face 47 of the tube 40. (See FIG. 22.) The ring 50 is interrupted at 51 to provide a beginning and an end for the ring 50, and terminals 52 and 53 are provided, one leading from each end. In this ring 50 and in each target described, it is preferable to have a generally radial conductive element at each end extend the radius of the annulus and providing a bus bar for the terminals. (See FIG. 3.)

This general type of target 50 is shown in the Cuniff Patent 2,374,666, issued May 1, 1945, but we have found that satisfactory results for our purposes cannot be obtained from the Cuniff device as there shown; largely because of the problem of secondary emission. When the electrons in a cathode-ray tube strike a target—such as the ring 50—secondary electrons are emitted from the target and move to another location either off the target or elsewhere in the target. Usually the secondary electrons emitted are more numerous than the primary electrons that strike the target; so where the circular sweep is rapid, (as it is when generated by an airplane engine) no sawtooth wave can be obtained from a structure like that shown in the Cuniff Patent No. 2,374,666. However, description of the several differences necessary to produce the desired results will be deferred until completion of the discussion of the general theory of operation of the invention.

In the form of the invention shown in FIG. 1, the ring 50 is made to have uniform resistance per length, by making it as shown in FIG. 3, constant in width and uniform in its material constitution. Hence, as the electron beam 45 starts at terminal 52, the resistance between the beam and the terminal 53 is at a maximum, or 100% of the ring's resistance. As the beam 45 moves, the resistance decreases uniformly. After the beam 45 has moved 90°, the resistance through the ring 50 has dropped 25%; when it has moved 180°, the resistance has dropped to 50%; at 270° the resistance is 25% (a drop of 75%); and when the beam reaches the terminal 53, the resistance across to the terminal 53 is zero. Thus, the circular beam 45, generated by two sinusoidal voltages 90° out of phase, results in a sawtooth sweep with a linear slope (see FIG. 10).

This sawtooth sweep, which may be amplified if necessary by an amplifier 54 may then be impressed on the main cathode-ray tube 55 of the analyzer, across its "horizontal deflection" plates 56, 57. This causes the electron beam of the tube 55 to move from left to right at the same rate as the engine cycle speed, and then to move practically instantaneously back from right to left (or vice versa, if desired). The rate of speed of the electron beam is constant if the engine speed is constant; if the engine speed changes, the speed of movement of the beam changes. Therefore, the position of the beam relative to the engine cycle is constant, with any given resistance ring. For example, when using the resistance ring 50, the sweep plates 56, 57 are impressed with a sawtooth sweep voltage in exact synchronization with the engine-driven two phase generator 32 and its circular sweep at the tube 40.

Across the other, "vertical deflection," plates 58 and 59 of the tube 55 are impressed the signal from the engine itself, which may be of the type shown in Patent 2,518,427 or may be of another type. The signal may be from an engine magneto (for studying ignition) or may be from a vibration pickup (as shown in FIG. 1), or any other engine-generated signal may be used.

(c) *Operation of the FIG. 1 apparatus.*—When the engine 30 is running, the two-phase generator 32 generates a circular sweep 46 at the tube 40, necessarily perfectly synchronized at every angular position with the engine cycle. This circular beam 46 impinging on the resistance ring 50 sets up an electrical circuit which changes the output voltage across the terminals 52 and 53 as the beam 46 passes around its circular path. This output voltage, properly amplified if necessary, is impressed across the sweep plates 56 and 57 of the analyzer cathode-ray tube 55 resulting in a sweep circuit there. Meanwhile, the signal plates 58, 59 are impressed with a signal from the portion of the engine being analyzed, as provided in my Patent No. 2,518,427 or in other engine analyzer circuits, giving a resultant pattern on the scope 55. When the engine is accelerated, both the engine-initiated signal and the engine-generated sweep always remain in perfect phase. The point of initiation thereof is varied by varying the positions of the two coils 41, 42 relative to the target 46.

(2) *A Preferred Cathode-Ray Tube For Generation of the Sweep (FIG. 2)*

The problems mentioned earlier have been solved by constructing the tube 40 as shown in FIG. 2. Secondary emission is suppressed by providing a grid 60 closely adjacent to the target 50, i.e., between about $\frac{1}{32}$ " and $\frac{1}{4}$ " from it. The suppressor grid 60 may comprise a screen of fine stainless steel wire having between 50% and 90% open area and maintained at a potential between about 50 and 200 volts negative with respect to the target 50. For example, if the target 50 is at a potential of about 2,000 volts, the suppressor grid 60 may be at a potential of about 1,800 volts, when it is located about one-eighth of an inch from the target 50.

The primary beam electrons which strike the suppressor grid 60 produce secondary electrons; these secondary electrons are all collected by the wall coating 72 (see below) whose potential is positive with respect to the suppressor grid 60. The primary beam electrons that penetrate the suppressor grid 60 strike the target electrode 50 and produce secondary electrons, but these secondary electrons are caused to return to the target electrode 50 by the electrostatic field between the suppressor grid 60 and the target electrode 50. It is important to insure that these secondary electrons return to a point close to their point of origin, in order to obtain high resolution of the signal and eliminate redistribution effects. The closeness of their return to their point of origin is determined by the strength of the electrostatic field, which may be increased either by decreasing the distance between the grid 60 and target 50 or by increasing the potential difference between these elements.

While the target 50 may be on the inside face 47 of the tube 40, it need not be, and for many uses it is better supported as shown in FIG. 2. Here, a stainless steel disc 61 is supported away from the face 47, as by lead wires 62, 63, 64, and 65 partly in combination with insulators 66, 67, and 68. A glass plate or ring 70 may be supported above the disc 61, as by lead wires 62 and 63 and insulators 66 and 67, and the ring 70 is coated to provide the target 50. The grid 60 may also be supported by the disc 61 and insulated leads 65 and 69. This structure assures that any secondarily emitted electrons will either return directly to the target 50, at substantially their original location, or will be carried to the disc 61.

The side walls 71 of the tube 40 are preferably painted

or otherwise coated at 72 with colloidal carbon or some other conductor, the coating 72 being kept at the same potential as the suppressor grid 60, to prevent dispersion of the electrons. For this coating, the type of colloidal carbon referred to by Cunniff ("sold under the trade-name 'Aquadag'") is quite satisfactory.

However, "Aquadag" is not satisfactory for the ring 50, because "Aquadag" is colloidal graphite made up of small discs or platelets of carbon that overlies each other with substantial areas of contact, and therefore the resistance is too small, resulting in too small a drop in potential and requiring excessive amplification. Colloidal lampblack, however, being made up of small spheres with small areas of contact, is satisfactory as the target material. This material is usually bonded to the glass 70 by silica, deposited from silicic acid or from the reaction of an acid on silicates, forming a gel that bonds the colloidal lampblack to the glass.

For many purposes, even better results can be obtained by using a stannic oxide coating. A solution of stannic chloride may be sprayed on hot glass; the hydrochloric acid formed is volatilized and stannic oxide deposits as a thin transparent layer bound to the glass by chemical formation. The desired pattern may be sprayed on directly, or the whole area of the face 47 or ring 70 or other supporting surface may be coated with stannic oxide and the unwanted portions removed, as by protecting the wanted area with a lacquer and reducing the tin oxide (as by sprinkling it with zinc powder and then with hydrochloric acid, to obtain nascent hydrogen) and washing off the reduced tin.

However, still better results can be obtained by depositing the whole face 47 or 70 (in a disc form) with tin oxide and etching out a fine line 73 around the desired area, leaving all the remaining tin oxide. This separation is sufficient to control the resistance, and the secondary emission effect from the remainder of the face 47 or other disc is better controlled by having a partial or full conductor coating than when glass, or other high-resistance material, surrounds the target.

Other semi-conductors may be used; for those that are photo-conductive, it will be necessary to paint the tube black or to operate in darkness. Tin oxide has the advantage that it is both transparent and does not exhibit photo-conductivity; so it can be operated in the light, and operation of the tube can be observed through the transparent tin oxide coating.

Different potentials are maintained on different elements of the tube by means of a voltage divider r , connected across a battery b . The leads 62 and 64 are at the highest potential, while the next highest potential is that of the coating 72, which is connected by a lead 74 to the second anode a_2 . The anode a_2 is connected to the first anode a_1 by a lead 74a, and the anode a_1 is connected to the voltage divider r by the lead 74b. The next lower potential is that of the lead 65. Then, the grid g_2 is connected by a lead 74c to the voltage divider r at a higher potential than the control grid g_1 , which is connected at the lowest end of the voltage divider r by lead 74d.

Thus, when the filament f is heated, the cathode c emits electrons controlled by the grid g_1 , they pass through three successive slits s_1 , s_2 , and s_3 in anodes a_1 and a_2 , receiving further control by the grid g_2 . Their deflection is determined in one direction by the plates p_1 and p_2 , and in the direction normal thereto by the plates p_3 and p_4 . The beam, moving in a circle due to the connection of the plates p_1 , p_2 , p_3 , and p_4 to the engine-driven generator, sends electrons toward the target 50. Secondary emission electrons are suppressed by the grid 60 and by the coating 72. As the beam moves in a circle around the target 50, the potential difference between the contacts 52 and 53 is determined by the specific resistance of the target 50, and the remainder of the circuit is substantially that shown in FIG. 1.

(3) Different Types of Resistance Rings and Their Corresponding Types of Sweeps (FIGS. 3 to 20)

Different types of resistance rings can be used to obtain different types of sweep circuits. To illustrate this principle, several different types of rings have been illustrated, together with some of their effects on the sweep and on the analyzer patterns.

(a) *Full 360° uniformly graduated ring 50 (FIGS. 3, 4, 10, 11, and 14).*—The ring 50, as stated earlier, has a uniform specific resistance, or resistance per length; so the resistance between the terminals 52 and 53 varies uniformly with angle over a full circle from 100% of the resistance value of the ring 50 to zero resistance. This gives a saw-tooth wave of the linear type, as shown in FIG. 10 by the curve 75.

If the beam 45 in the auxiliary tube 40 moves in the opposite direction, it will move the sweep in the main tube 55 from right to left instead of left to right, since the resistance on the ring will then start at zero and gradually increase at a uniform rate.

The 360° extent of the ring 50 means that it will read the full 720° of rotation of the engine crankshaft cycle, which corresponds to one complete engine cycle. Thus, in an ignition diagram 76 such as that shown in FIG. 11, patterns for every cylinder appear. The same thing happens in the radio-frequency ignition pattern 77 shown in FIG. 14, where there are gaps 78 between each cylinder's diagram.

FIG. 4 shows how the ring 50 can be made to extend the full 360°. Here it will be noted that the surface of the ring 50 is not planar, and that the terminal 52 is isolated from the terminal 53 by being on a different level. In fact, the portion 79 is undercut below a portion of the ring 50.

(b) *Short-arc uniformly graduated ring 80 (FIGS. 5 and 12).*—The ring 80 shown in FIG. 5 is adapted to enlarge a portion only of the complete engine cycle and to exclude the rest of the cycle. This makes it possible to enlarge the diagram for each cylinder one cylinder at a time and study it more thoroughly. Thus, in an 18-cylinder engine, a segment 81 extending 20° of arc will cover one-eighteenth of the complete engine cycle, having terminals 82 and 83 at the opposite ends, and the pattern of one cylinder will take up the whole face of the tube 55.

The segment 81 is of uniform resistance per length, from a 100% resistance when the beam 45 is at 0° to zero resistance at 20°. The ring 81 may be narrower than the ring 73, in order to increase its resistance per unit length, or a different type of resistance material may be used, with a higher specific resistance, or the same material may be spread less densely on its insulator backing, in order to give the same end result of increased resistance per unit length. The large 340°-angle portion 84 that remains may be an open circuit to give full resistance, or be connected through a fixed high resistance, or it may be a fully conductive element to give zero resistance. Either construction gives the same end result at the sweep at the tube 55. The resultant curve 85 on the FIG. 10 diagram shows a steep linear slope extending for 20° and then perfectly flat for the remaining 340°. This assumes that the portion 84 is conductive and that it is connected through a high resistance equal to 100% of the target resistance.

A typical ignition pattern 86 obtained from one cylinder by using the ring 80 is shown in FIG. 12, where it will be seen to be a greatly enlarged (spread-out) version of one-eighteenth of the FIG. 11 pattern.

(c) *Gap-eliminating ring 90 (FIGS. 6 and 15).*—The ring 90 shown in FIG. 6 is of a novel type, designed for use with radio-frequency analyzer ignition circuits to solve the problem indicated in FIG. 14, where there are gaps 78 in the pattern between each cylinder. If there normally were no gaps like this, then the presence of a

gap for a whole cylinder would more clearly indicate trouble that should be given immediate attention. (Reference, Lindberg application S.N. 460,305, filed October 5, 1954, and now Patent No. 2,959,732.)

So the ring 90 provides two types of segments 91 and 92 that alternate. Each segment 91 is made from conductive element (e.g., a metal deposit). Thus, in an eighteen-cylinder engine, there are eighteen segments 91, whose length corresponds to the gaps 78 in the curve of FIG. 14. On the other hand, the eighteen segments 92 are uniform resistance elements and correspond to actual firing time. Only two terminals 93 and 94 are provided, at each end of the target 90.

As a result, during each cycle, the voltage level will vary uniformly during the scanning of each segment 92 and will be unchanged during the scanning of each segment 91. The curve 95, shown in FIG. 10, results with sloped portions corresponding to the segments 92 where the voltage increases, and level horizontal portions correspond to the segments 91. This means that the sweep at the cathode-ray tube 55 will move in jerks, eliminating the level portions 91 to zero length. Because of this, the signal that produces the R-F diagram 77 of FIG. 14 when using the ring 50 will produce the R-F diagram 96 in FIG. 15 when the ring 90 is used. The gaps 78 that show on the diagram 77 are eliminated, and the curve appears as continuous, under normal conditions. Trouble is therefore easily spotted, as is shown in FIG. 15, where the missing portion 97 means that one cylinder gave no R-F signal, being shorted out. This shows much more clearly and is more easily detected than the missing portion 98 in the diagram 77.

(d) *Half-and-Half slow-fast rings 100 and 110 (FIGS. 7, 8, and 13).*—A different type of ring 100 shown in FIG. 7 makes it possible to scan the complete engine while also picturing one cylinder of the engine in expanded form, i.e. fast sweep. The sweep pattern produced by the ring 100 spreads out the diagram of that cylinder without omitting the diagram for any cylinder. By using a cylinder-cycle selector switch, the engineer can continue to watch the complete engine cycle while examining each individual cylinder in detail, one at a time, going from cylinder to cylinder.

In the ring 100, a segment 101 (which in an eighteen-cylinder engine will extend 20°) is of uniform width and is relatively narrow as compared with the remaining segment 102 (which in this example will occupy 340°). Half the resistance drop occurs during the 20° segment 101, and the other half of the resistance drop occurs on the 340° segment 102. Terminals 103 and 104 are provided at the opposite ends of the ring 100. As a result, the curve 105 shown in FIG. 10 is obtained, having a steeply sloped portion 106 extending the first 20° and a more flatly sloped portion 107 extending the remaining 340°.

In order to illustrate one type of diagram that may result from the ring 100, FIG. 13 is included. Here a diagram 108 clearly shows one cylinder occupying one-half 109 of the screen while the remaining seventeen cylinders occupy the remaining half 110 of the screen.

It should be noted that the diagrams shown in FIGS. 11, 12, and 13 are all obtained from the same basic engine signal. Thus, the FIG. 11 diagram 76 shows all eighteen cylinders, and each one occupies the same length; the FIG. 12 diagram 86 shows one cylinder only, and in the FIG. 13 diagram 108, half the picture is occupied by one cylinder and the remaining half by the other seventeen cylinders. Note that FIGS. 11 and 13 show one of the engine spark plugs with an open secondary circuit at 99. If further investigation of this particular cylinder is desired, it can be obtained by shifting the initiation of the sweep in FIG. 13 to bring the signal for that cylinder into the position where it occupies the left half of the diagram. Or the ring used for the FIG. 12 pattern may be used.

FIG. 8 shows another ring 111 with terminals 112 and 113 that will accomplish the same results as the ring 100 and has the same characteristic curve 105. Instead of having a narrow segment 101 and a wide segment 102 of the same specific resistance, the ring 110 has a segment 114 of the same width but more specific resistance than a longer segment 115. This may be obtained by using two different-resistance materials, or it may be obtained by depositing the same resistance material less densely in the segment 114 and more densely in the section 115.

(e) *A non-linear ring 120 (FIG. 9).*—So far, all the rings referred to give linear sawtooth waves, square waves or mixtures of those basic types. Obviously, the invention is not so limited, and to illustrate the possibilities, FIG. 9 shows a ring 120, the thickness of whose resistance element 121 varies, to give, across terminals 122 and 123, a non-linear curve 124 in FIG. 10. Since the element 121 gets wider and wider, moving from 0° to 360°, the slope of the curve continues to increase. The resultant sweep spreads the initial part of the cycle and gradually compresses the later parts. The same results can be obtained by non-uniform distribution of resistance coating over a uniform width resistance segment.

(f) *A multiple-band ring 130 (FIG. 16).*—It is possible to obtain the results of several, or indeed all of the rings shown, on a single disc or tube face by providing a plurality of annular bands, each band being constructed in a different way. This principle is illustrated by a multi-band element 130 shown in FIG. 16. Here three bands 131, 132, 133, are shown, though there could as well be two, four, five, or any other number of bands.

The outer annular band 131, with its terminals 134 and 135, is like the ring 50 in FIG. 3, that is, it is of uniform width and varies at a constant rate from 100% resistance to zero resistance over the full 360° circle. The next inner band 132 with its electrodes 136 and 137, is graduated exactly like the band 81 shown in FIG. 5, that is, from full resistance to zero resistance in a 20° arc 138, with the remaining 340° arc 139 at full or zero resistance. The innermost band 133, with its terminals 140 and 141 is graduated like the ring 100 in FIG. 7, that is, from 100% resistance to 50% resistance in a 20° segment 142 and uniformly from 50% to zero resistance in the remaining 340° segment 143.

The composite wedge 130 is used by providing a voltage regulator and a selector switch that will act to vary in some manner the voltage impressed across the deflector means of the circle-sweep-cathode-ray tube. One such arrangement is shown in FIG. 21 (to be explained later on in more detail) where an amplified engine-generated current is sent through a selector switch 230 comprising a variable step-resistor having three positions, each one of which determines a given radius of the circular sweep and thereby sends the beam to any one of three predetermined radii corresponding to the three bands of the ring 130. The circuit arrangement will be explained in more detail later on. Other means for varying the voltage could be used, and this example illustrates how a single disc may incorporate several different sweep circuit arrangements.

(g) *Indexing the sweep curve (FIGS. 17 to 20).*—The invention also makes it possible to provide indexing means in connection with any of the rings so as to calibrate the pattern at the scope 55. This can be done by providing the ring itself with radial slot lines where there is no resistance material. Therefore, substantially zero contact is made, and the resistance increases to maximum briefly. For example, FIG. 17 shows a ring 150 like the ring 50 but with four openings or blank areas 151 spaced around it at regular (90°) intervals. When the electron beam 45 strikes one of these areas 151, it passes through without making substantial contact with the ring 150 correspondingly affecting the sweep. This is shown graphically in curve 153 with its dips 154 (see FIG. 19) and showing as gaps 155 in FIG. 20. These dips 154

produce zero voltage at a particular horizontal sweep location on the picture tube 55, corresponding to the degrees of arc where the lines are formed in the ring, and therefore to corresponding degrees in the engine cycle.

To get the sharp breaks shown in FIGS. 19 and 20, it is advisable to connect the terminals 156 and 157 in the manner shown in FIG. 18. As will be seen, the display tube 55 is again set up with one pair of its deflection plates 58 and 59 connected across the engine-initiated signal and its other deflection plates 56 and 57 connected across the resistance element. A capacitor 158 is connected between the terminal 156 and the deflection plate 56, and a capacitor 159 is connected between the deflection plate 57 and the terminal 157. A lead 160, with a capacitor 161, connects the terminal 156 to the control grid 162 of the cathode-ray tube 55. This entirely suppresses the emission of the beam in the tube 55 whenever the beam in the auxiliary tube passes across one of the slits 151.

(4) *A More Complex Analyzer Circuit (FIG. 21)*

To give some further indication of the versatility of this invention, we shall now describe a more complex circuit that takes advantage of some of the special features of our system wherein the sweep circuit of the engine analyzer tube is generated across a resistance ring or band by a circular sweep in an auxiliary cathode-ray tube. Several features of this circuit are substantially identical with that of the simple circuit of FIG. 1, while other features have been shown in modified form to illustrate alternate methods of accomplishing the same end results. In other instances, the refinements described are completely absent from the simple circuit shown in FIG. 1.

The circuit and apparatus shown in FIG. 21 are adapted for use with multi-engine aircraft and are therefore shown in connection with four engines herein called engines A, B, C, and D, respectively. In each instance, the engine A, B, C, or D rotates a magnet 200a, 200b, 200c, or 200d of a three-phase generator 201a, 201b, 201c, or 201d, each driven at engine cycle speed; i.e., at one-half the crankshaft speed in a four-cycle engine. From poles 202, 203, and 204, of each generator 201a, 201b, 201c, or 201d, current is transmitted to a resolver 205a, 205b, 205c, or 205d, each of which provides two sine waves 90° out of phase and adjustable relative to the engine generator 201a, 201b, 201c, or 201d to time engine A, B, C, or D to its generator. The resolver, in effect, is a continuous resistor with four brushes 206, 207, 208, and 209 mounted 90° apart and linked together mechanically as a unit. Electrical insulation is provided so that the brushes 206 and 207, which are diametrically opposite each other, supply the current pickup which eventually will be impressed on the horizontal deflection plates 211 and 212 of the cathode-ray tube 210, while the brushes 208 and 209, also diametrically opposite each other, pick up the current which will ultimately be used on the vertical deflection plates 213 and 214. The resolvers are separately adjustable in rotation to time each engine to the analyzer, and are mechanically tied together so that rotation of cylinder-cycle selector switch 215 rotates all resolvers together and so times the sweep signal of all engines to the analyzer.

An engine selector switch 220 is provided into which each of the four leads 221a, 222a, 223a, and 224a; 221b, 222b, 223b, and 224b; 221c, 222c, 223c, and 224c; and 221d, 222d, 223d, and 224d from each of the resolvers 205a, 205b, 205c, and 205d lead. The selector switch 220 provides a means for placing the four leads of any one engine into contact with corresponding output leads 225, 226, 227, and 228, the leads from other three engines leading at that time to a dead end or broken circuit. The four leads 225, 226, 227, and 228 lead through suitable amplifying and automatic voltage-regulating means 229

to a sweep selector switch 230 which has been mentioned above. It comprises four step resistor elements 231, 232, 233, and 234 (one for each of the four leads 225, 226, 227, and 228) all linked together for step movement so that all the resistor elements 231, 232, 233, and 234 of the switch are either at step 1, or step 2, or step 3. This varies the voltages in the lead lines 225, 226, 227, and 228 and therefore varies the voltage impressed upon the deflection plates 211, 212, 213, and 214 of the cathode-ray tube 210, which in turn vary the deflection of the cathode-ray 235 to give it any of three desired radii.

Except for the refinements heretofore described, the cathode-ray tube 210 operates substantially the same as the tube 40 to give a circular sweep 236 although in this instance the circular sweep 236 may be adjusted to any one of three radii.

The cathode ray 235 impinges on the resistance element 130 and by operation of the sweep selector switch 230, it is possible to send the beam 235 upon any one of the three bands 131, 132, 133 of the wedge 130. From there suitable leads 237, 238 may conduct the resultant electric current through an amplifier 239, if needed and desirable, to the main cathode-ray tube 240 of the engine analyzer, where it is impressed upon the sweep plates 241 and 242.

The initiation of the cycle for each engine A, B, C, and D may be controlled by its resolver 205a, 205b, 205c, and 205d which may be synchronized to the engine once and for all, and left there, or may be made adjustable at any time, by rotating the four brushes in tandem.

If desired, instead of tying all four resolvers together as shown above, an additional cycle selector switch may be inserted between the engine selector switch 220 and the amplifier 229. Once each engine has had its cycle synchronized to that of the other engines by adjustment of the resolvers 205, cycle initiation for all engines may be varied by using this single switch.

Many types of engine signals may be analyzed, and for purposes of illustration, a typical condition switch 250 is shown diagrammatically with 36 conditions possible, including eight for each engine (or 32 altogether) connected thereto at 251a, 251b, 251c, and 251d, three for coupling engine A to each of the other three engines, and one special switch. Typical uses of the analyzer are illustrated by the labels on the lines leading from Engine D (using circuit connections as described in Lindberg Patent 2,518,427) showing that there is a magneto pickup for ignition analysis, a temperature pickup, a pressure pickup, a vibration pickup, a motion pickup, a torque pickup, and a propeller dynamic balance velocity pickup. Any one of these pickups may be selected at the condition switch 250 for any of the engines A, B, C, and D. The engine selector switch 220 is connected to and operated by the condition selector switch 250 so that the proper engine always initiates the sweep. The switching arrangement shown in Patent 2,518,427 may be read on the selector switch.

(5) A Modified Form of Apparatus

As has been stated earlier, a tin oxide coating is transparent. This fact may be taken advantage of by using an apparatus like that shown in FIGS. 22, 23, and 24, where a tin oxide target 301 is provided on the inner face 47 of the tube 300. Actually, substantially the face 47 is completely covered with tin oxide to provide an inner tin oxide anode 302 and an outer tin oxide anode 303 divided from the target electrode 301 by narrow gaps 304 and 305 respectively. A suppressor grid 310 substantially identical to the suppressor grid 60 shown in FIG. 2 is provided at the proper distance from the tin oxide coating, and the inner wall 311 of the tube 300 has a graphite ("Aquadag") coating 312. So far, the elements described merely provide an equivalent structure to that shown in FIG. 2 and are substantially the elements initially described in connection with FIG. 1.

The first difference in the modified apparatus is the addition of a luminescent coating 320 which may be of

the normal phosphor type used in cathode-ray oscilloscopes, so that the path of the electron beam is visible and can be observed through the transparent tin oxide coatings 301, 302, and 303, and the glass wall of the tube 300. This factor alone makes it easier to monitor the position of the electron beam relative to the resistance element 301. However, still further advantages may be obtained by providing, in addition to all these elements, a central electrode 330, which is connected by a lead 331 to an engine-initiated signal.

Preferably the target 301 is similar to the target exhibited in FIG. 5 in providing a segmental shape and in this instance, of course, the coatings 302 and 303 are actually one continuous coating with an indentation where two portions are separated only by the segmental target 301.

The resultant appearance of the device during operation is shown in FIG. 23 where the target 301 is indicated by dotted lines. A circular sweep is still provided in the curve 340, but this circular sweep has been modulated to carry the complete engine-ignition diagram of all the signals. In other words, this curve corresponds generally to that shown in FIG. 11, although it is arranged around the circular sweep pattern instead of being spread horizontally across the diameter of the tube. By providing the resistance element 301 in this circularly displayed diagram and by connecting the target 301 as shown in FIG. 24, to the deflection plate 345, the pattern of any one cylinder may be displayed on the second display tube 350 at the same time that the complete pattern is displayed on the tube 300. Thus, a very economical method of getting both a large pattern of a single cylinder and a large diagram of all cylinders simultaneously can be provided.

To those skilled in the art to which this invention relates, many changes in construction and widely differing embodiments and applications of the invention will suggest themselves without departing from the spirit and scope of the invention. The disclosures and the description herein are purely illustrative and are not intended to be in any sense limiting.

We claim:

1. In an engine analyzer, engine-operated means to generate a generally circular cathode-ray sweep beam in cycle with its engine; an annular segment resistance target upon which said beam impinges, said target having a pair of terminals, one at each end thereof; a suppressor grid closely adjacent said target; means to keep said grid potential negative with respect to said target; an envelope enclosing said target and grid, said envelope having a conductive coating on its interior side walls; means for keeping the potential of said coating positive with respect to said target, so that the motion of said sweep generates a potential difference across said terminals that varies with the angular position of said beam and is unaffected by secondary emission phenomena; an engine analyzer tube having sweep plates; and means to impress said potential difference across said sweep plates.

2. In an engine analyzer, engine-operated means to generate a circular cathode-ray sweep beam in cycle with the engine that generates it; an annular-segment resistance target against which said beam impinges, having a terminal at each end so that the potential difference between said terminals varies with the position of said beam; a suppressor grid closely adjacent said target; means to keep said grid potential negative with respect to said target; an envelope enclosing said target and grid, said envelope having a conductive coating on its interior side walls; means for keeping the potential of said coating positive with respect to said target; an engine-analysis cathode-ray tube having two mutually perpendicular pairs of parallel deflection plates; means to obtain an analyzer signal from some portion of the same engine and to impress it across one pair of deflection plates; and means to impress a multiple of said potential difference across the other pair of deflection plates whereby a clean sweep sig-

nal is obtained, unaffected by secondary emission, thereby enabling clear analysis at high engine speeds.

3. The analyzer of claim 2 in which said target describes 360°, its terminals being separated by a break in said annulus and a displacement thereof, there being an actual overlap of one end by the other to avoid any break in continuity so far as the beam is concerned, so as to develop a full-engine cycle sawtooth sweep for the engine analysis sweep plates.

4. The device of claim 2 in which said target comprises a short annular segment and a long segment of very high resistance, so as to develop a sawtooth sweep for a short portion of the engine cycle across said sweep plates.

5. The device of claim 2 in which said target comprises a substantially 360° ring having each of a series of radial resistance segments alternating with each of a series of radial conductive segments.

6. The device of claim 2, wherein a 360° target has one portion whose specific resistance is substantially different from the specific resistance of another portion.

7. The device of claim 2 wherein a 360° target varies non-linearly in its resistance between terminals relative to angle of cycle.

8. The device of claim 2 wherein there are a plurality of annular segment targets, and means to vary the radial levels of said circular beam.

9. The device of claim 2 wherein there are discontinuous isolated portions of said target swept by said beam, and whereby said terminals are also connected across a grid in said engine analysis tube, whereby blank indexing portions are provided in the engine analysis sweep.

10. In an engine analyzer, engine-operated means to generate a generally circular cathode-ray sweep beam in cycle with the engine that generates it; means to vary the potential difference between two points on the circle swept by the beam according to the angular position thereof; an engine-analysis cathode-ray tube, having sweep plates; and means to impress a multiple of said potential difference across said sweep plates.

11. In an engine analyzer, engine-operated means to generate a non-overlapping cycle-path cathode-ray sweep beam in cycle with its engine; a resistance target corresponding to said path upon which said beam impinges, said target having a pair of terminals, one at each end thereof, so that the motion of said sweep generates a potential difference across said terminals that varies with the angular position of said beam; a suppressor grid closely adjacent said target; means to keep said grid potential negative with respect to said target; an envelope enclosing said target and grid, said envelope having a conductive coating on its interior side walls; means for keeping the potential of said coating positive with re-

spect to said target, whereby the sweep beam is not distorted by secondary emission phenomena; an engine analyzer tube having sweep plates; and means to impress said potential difference across said sweep plates.

12. In an engine analyzer, engine-operated means to generate a non-overlapping cycle-path cathode-ray sweep beam in cycle with the engine that generates it; a resistance target corresponding to said path against which said beam impinges, having a terminal at each end so that the potential difference between said terminals varies with the position of said beam; a suppressor grid closely adjacent said target; means to keep said grid potential negative with respect to said target; an envelope enclosing said target and grid, said envelope having a conductive coating on its interior side walls; means for keeping the potential of said coating positive with respect to said target, said suppressor grid and coating thereby preventing secondary emission electrons from impinging on said target and affecting the sweep potential; an engine-analysis cathode-ray tube having two mutually perpendicular pairs of parallel deflection plates; means to obtain an analyzer signal from some portion of the same engine and to impress it across one pair of deflection plates; and means to impress a multiple of said potential difference across the other pair of deflection plates.

13. The device of claim 2 in which said target is supported on a separate element away from the end wall of the tube.

14. The device of claim 2 in which said target comprises a second coating of resistance material on the inside face of the end wall of said tube.

15. The device of claim 14 wherein the coating includes luminescent material.

16. The device of claim 2 in which there is a central electrode parallel to the axis of the electron beam.

References Cited in the file of this patent

UNITED STATES PATENTS

2,369,749	Nagy	Feb. 20, 1945
2,374,666	Cunniff	May 1, 1945
2,518,427	Lindberg	Aug. 8, 1950
2,607,903	Labin	Aug. 19, 1952
2,675,499	Sears	Apr. 13, 1954
2,740,069	Minto	Mar. 27, 1956
2,795,727	Haefl	June 11, 1957
2,818,523	Johnson et al.	Dec. 31, 1957
2,863,088	Barbier	Dec. 21, 1958
2,867,766	Broder et al.	Jan. 6, 1959

FOREIGN PATENTS

156,352	Australia	May 5, 1954
---------	-----------	-------------