

April 15, 1958

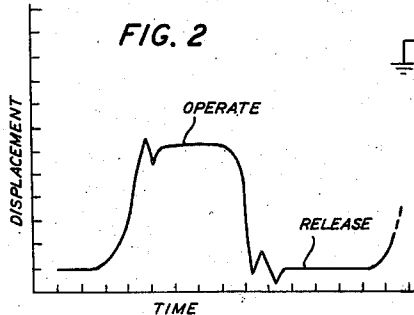
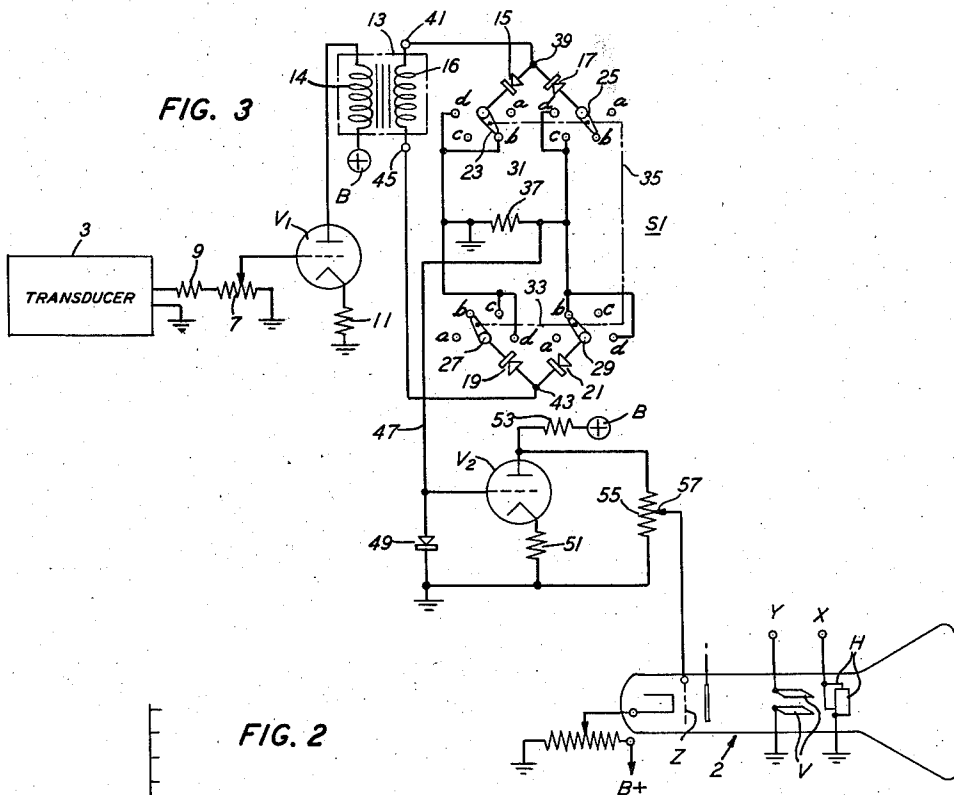
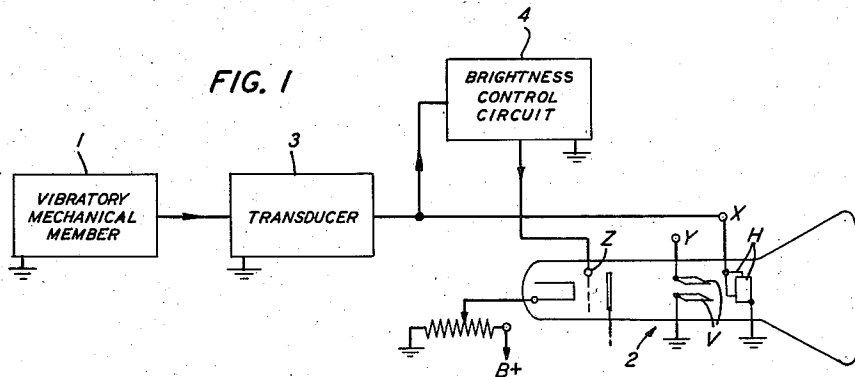
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2,831,161

CATHODE RAY TUBE DISPLAY

Filed May 17, 1954

4 Sheets-Sheet 1



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4 Sheets-Sheet 2

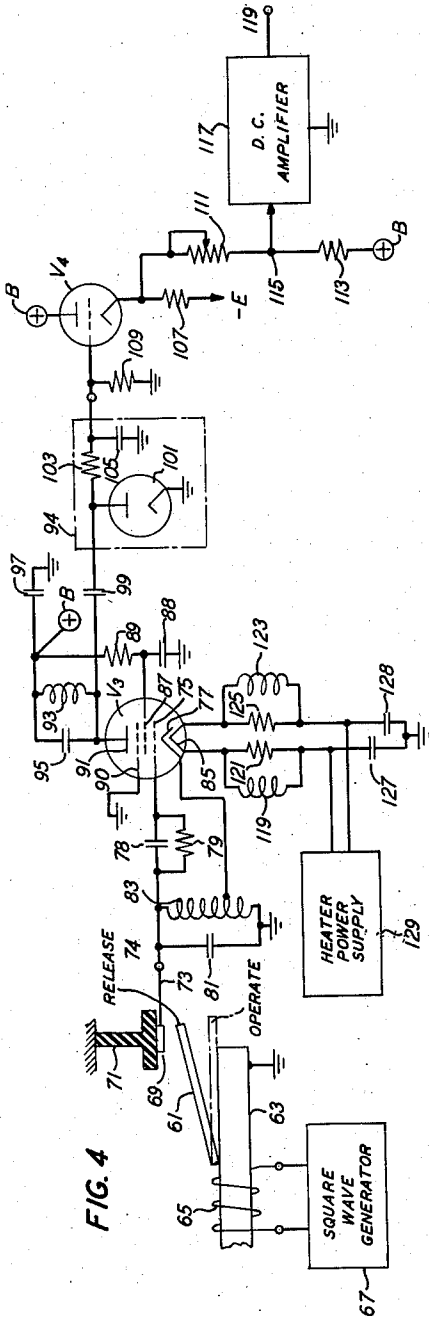


FIG. 4

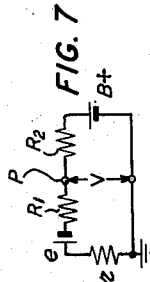


FIG. 5

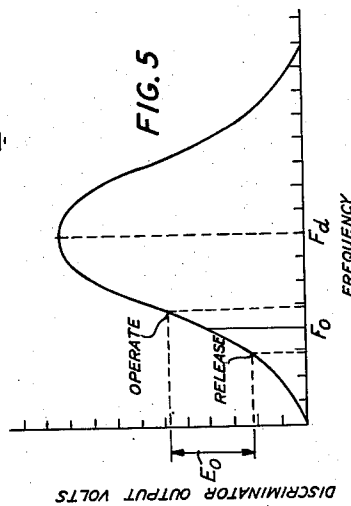
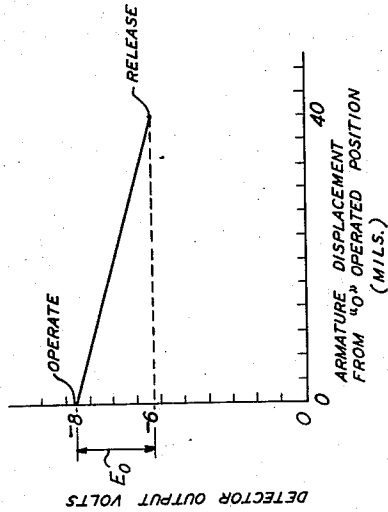


FIG. 6

FIG. 7



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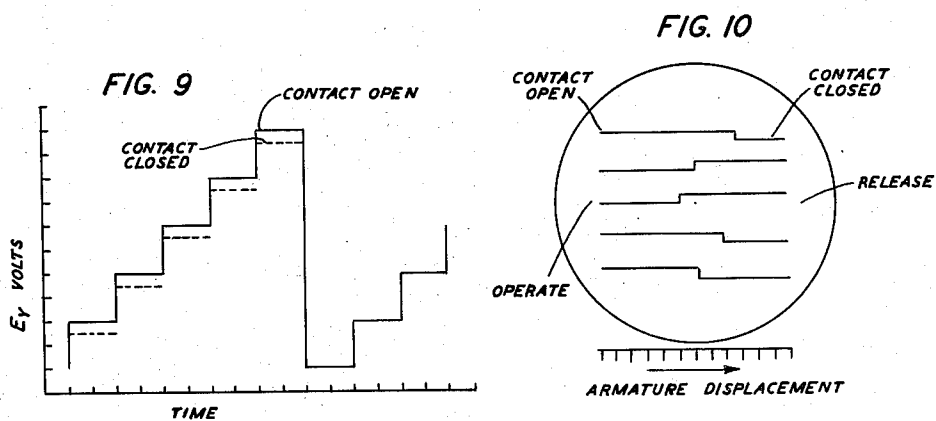
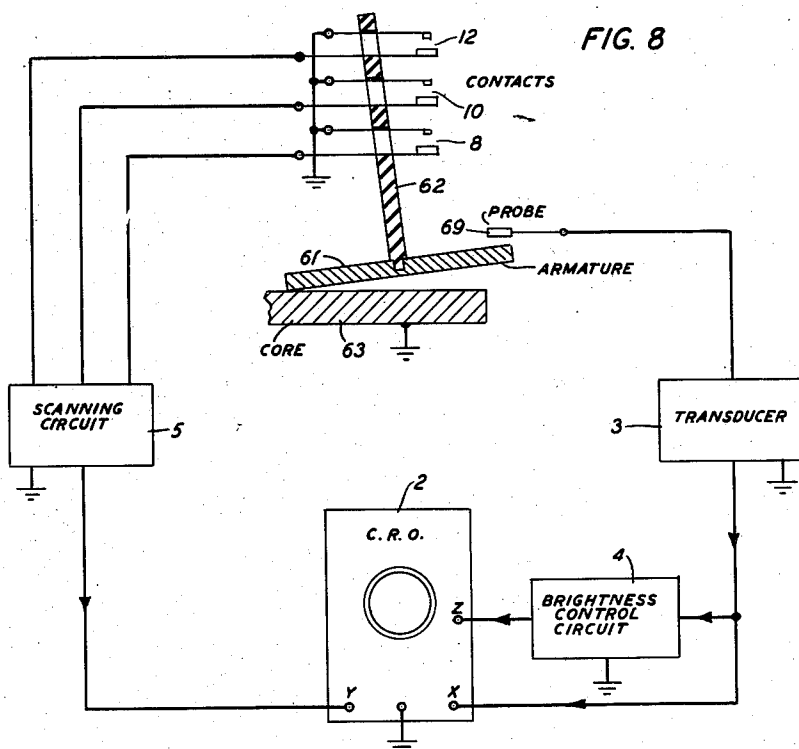
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4 Sheets-Sheet 3



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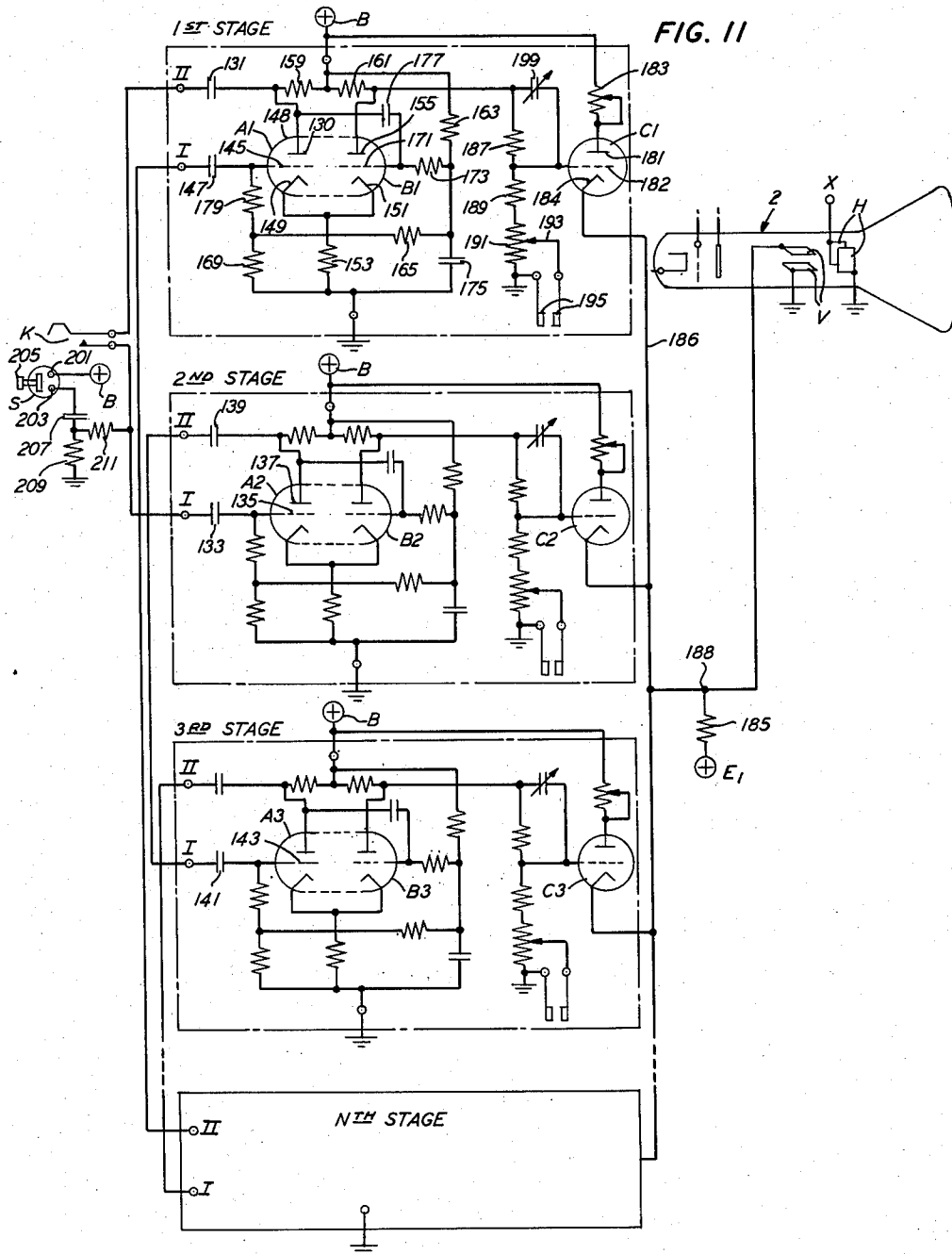
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CATHODE RAY TUBE DISPLAY

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Application May 17, 1954, Serial No. 430,146

4 Claims. (Cl. 324—28)

This invention pertains to display systems, and more particularly to a display system wherein the deflection of a cathode ray beam is controlled by an oscillatory voltage signal having recurrent quiescent intervals in its oscillatory cycles.

Dynamic relay testing devices are known wherein the relay armature is utilized as it continuously vibrates between its operate and release positions to develop a voltage of a magnitude proportional to the instantaneous displacement of the armature from one of these positions, and this voltage is applied to control the horizontal deflection of the cathode ray beam of an oscilloscope. In this manner, the displacement from its undeflected position of the spot produced by the beam on the oscilloscope screen is indicative of the displacement of the relay armature from its full operate or release position, depending on which is chosen as the reference position. The contacts operated by the relay armature, when they close or open in response to the armature motion, change the magnitude of an otherwise constant voltage which is applied to establish the vertical deflection of the cathode ray beam. As a result, when the relay armature is energized there is depicted on the cathode ray tube screen a horizontal line with a vertical step on the line indicating contact operation. If the relay armature is caused to continuously cycle between its operate or release position at a sufficiently rapid rate, the line will be repetitively retraced rapidly enough so the screen persistence will make the line appear to be constantly present. This enables the making of measurements on the screen which are indicative of the operating characteristics of the relay. The horizontal distance of the vertical step on the line from the position of the spot produced by the cathode ray beam when the relay armature is in the reference position indicates the precise position of the armature in its path of travel at which contact operation occurred.

Measurement of this characteristic of a relay becomes especially important in the case of high speed multicontact relays, since slight errors in contact separation or spring tension can cause improper operation of the contacts, and therefore of the multiple circuits controlled by the contacts. A relay testing device of the type described which is applicable for providing simultaneous display of the operation of each contact pair of a multicontact relay is disclosed in the copending application of Raymond W. Brown, Serial No. 357,876, filed May 27, 1953, now Patent No. 2,805,389. As described in detail in that application, a transducer responsive to armature displacement provides a voltage which is linearly proportional to armature displacement. This voltage is applied to the horizontal deflection electrodes of a cathode ray tube. A rapidly cycling electronic ring counter circuit successively actuates each of a plurality of vertical deflection tubes which provide a stepwave voltage to actuate the vertical deflection electrodes of the cathode ray tube. Each of the vertical deflection tubes is responsive to closure of a particular pair of the multiple

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contact pairs to alter the magnitude of the voltage of the step in the complete stepwave contributed by that deflection tube. The ring counter goes through many complete cycles in the time the relay armature takes to move between the full release and full operate positions, and the relay armature is caused to continuously vibrate between these positions. Hence, the display produced on the screen of the cathode ray tube is a series of horizontal lines, each line identified with a particular contact pair, and with a vertical jog on a line marking the instant of closure of the contact pair identified with that line. The horizontal displacement of the vertical jog on any line from the left end of the line, which is where the cathode ray beam hits the screen when the armature is in full release position, indicates the point in the operating path of the armature at which that contact pair closed.

While this device will give highly satisfactory performance, the fact that the relay armature is either at the full release or full operate position for a relatively long part of each oscillatory cycle, due to the normal inertia of the armature and the inherent inductance of the relay operating coil, makes the spots at the extreme ends of the cathode ray tube screen trace so bright relative to the remainder of the trace that the entire screen is fogged. This makes it difficult to see and measure the contact closure jogs on the relatively weak lines caused by the motion of the armature. The highly accurate adjustments required for high speed multicontact relays makes it highly desirable to be able to measure the position of the armature at which closure of each pair of contacts occurs with an accuracy of about a mil. Such accuracy of measurement would be practically unattainable unless the fogging effect is eliminated.

A very similar problem will be present in any system of cathode ray tube display of the position of a rapidly vibrating mechanical member, and more generally whenever an oscillatory magnitude voltage signal utilized to control the deflection of a cathode ray tube beam has relatively long quiescent intervals in its oscillatory cycles.

Accordingly, an object of this invention is to prevent the appearance of excessively bright spots on the screen of a cathode ray tube due to relatively long intervals of constant magnitude in cycles of an oscillatory magnitude voltage signal utilized to control the deflection of the cathode ray beam.

A further object is to prevent fogging of the screen of a cathode ray tube utilized to display the instantaneous position of a vibrating mechanical member due to relatively long stationary intervals in the vibrating cycles of the mechanical member.

A further object is to provide an improved dynamic testing device for multicontact relays which will simultaneously display the operating characteristics of all the relay contacts and permit highly accurate measurement of relay armature position relative to contact operation.

One feature of the invention is the derivation of a voltage representative of the instantaneous velocity of a vibrating mechanical member from a voltage representative of the instantaneous displacement of the mechanical member from a reference position, and the utilization of these voltages to provide a clear, unfogged display of the instantaneous displacement of the member on the screen of an oscilloscope.

A further feature of the invention is a free cycling electronic scanning circuit adapted for scanning each pair of a multiplicity of pairs of contacts actuated by a relay armature and for simultaneously displaying on the screen of an oscilloscope the instant of opening and closing of each contact pair as the armature vibrates between its fully released and operated positions.

An additional feature of the invention resides in the provision of a simplified, highly accurate single capacitive probe transducer which develops a potential linearly proportional to the displacement of a vibrating mechanical member from a reference position in its vibratory path.

Other objects and features of the invention will become apparent from a reading of the following detailed description and accompanying drawings in which:

Fig. 1 is a block diagram indicating the interconnections of the components of the invention in a preferred embodiment;

Fig. 2 is a graph of the displacement of a continuously vibrating mechanical member from its release position plotted against time;

Fig. 3 is a diagram of the cathode ray beam brightness control circuit;

Fig. 4 is a diagram of the electrical circuit and mechanical arrangement of the novel transducer utilized in applying the invention to relay testing;

Fig. 5 is a graph of the frequency variation of the output voltage of the detector circuit included in the transducer;

Fig. 6 is a graph of the variation of the output of the detector circuit included in the transducer plotted against the displacement of a vibrating mechanical member under test from its reference position;

Fig. 7 is a diagram of a simplified circuit equivalent of the cathode follower and potentiometer zero setting combination included in the transducer;

Fig. 8 is a block diagram showing how the invention may be utilized for dynamic gauging of a multicontact relay;

Fig. 9 is a graph of the stepwave voltage applied to the vertical deflection electrodes of the cathode ray oscilloscope by the free cycling electronic scanning circuit;

Fig. 10 is a representation of the image that appears on the oscilloscope screen when the invention is utilized for relay testing; and

Fig. 11 is a diagram of the free cycling electronic scanning circuit.

Referring now to Fig. 1, the "vibratory mechanical member" designated in block 1 represents the continuously vibrating object under test, the instantaneous position of which in its vibratory path of motion is to be displayed on the screen of the cathode ray oscilloscope 2. The oscilloscope is provided with suitable quiescent grid to cathode bias in a conventional manner, the one shown being connection of the cathode through a potentiometer to a source of positive direct-current potential B+. The "transducer" designated in block 3 represents a device which develops an output voltage which varies linearly with the instantaneous position of the vibratory mechanical member. One such device is described in the above-mentioned copending application, Serial No. 357,876. However, for relay testing the present invention contemplates use of a simplified transducer described in detail in the ensuing paragraph of this specification.

The transducer output voltage is applied to the active terminal X of the horizontal deflection electrodes H—H of the cathode ray oscilloscope 2. The transducer output voltage is such that the cathode ray beam is deflected to the left-hand portion of the screen of the oscilloscope when the mechanical member under test is at one extreme of its vibratory path and is deflected to the right-hand portion of the screen when the member is at the opposite extreme of its vibratory path. Hence, the instantaneous displacement of the spot produced on the screen by the cathode ray beam from either of its most extreme positions represents the instantaneous displacement of the mechanical member under test from the corresponding extremity of its vibratory path.

The time variation of the displacement of a rapidly vibrating mechanical member moving between relatively

closely spaced path extremities will be as depicted by the curve shown in Fig. 2. The horizontal portions of this curve, which evidently occupy a great portion of the time of each vibratory cycle, represent the displacement of the member when it is at the extremities of its vibratory path. The climbing and falling portions of the curve represent the intervals when the member is moving from release to operate position or the reverse. The regions designated "operate" and "release" on the graph are purely arbitrary, and are included only for definiteness in designating the extremities of the path of motion of the member. The transient oscillations at the ends of the horizontal portions of the graph are due to the inertial bounce which occurs at the instants when a repetitively activated and deactivated mechanical member reaches its fully operated or released position.

Since the transducer output voltage has the same form as the displacement curve of Fig. 2, unless further provision is made in the arrangement thus far described, the spot produced on the cathode ray oscilloscope screen in response to application of the transducer output voltage to the horizontal deflection electrodes will be at the extreme deflected positions for a large part of the time of each cycle of the spot from one of these positions to the other. The result will be great relative brightness of the spots at these extremes as compared to the brightness along the line of travel of the spot between them. This unevenness in brightness would cause fogging of the entire screen. The brightness control circuit designated in block 4 eliminates this condition by modulating the grid voltage of oscilloscope 2 with a voltage which increases the grid potential when the mechanical member under test is in motion and decreases the grid potential when the member is at rest, as it is at the extremes of its operating path. As is well known, the grid of an oscilloscope controls the brightness of the spot produced on the oscilloscope screen, a more positive grid potential causing an increase in spot brightness and so an increase in brightness of the display on the oscilloscope screen. The brightness control circuit operates by differentiating the output voltage of the transducer to obtain a voltage representative of the instantaneous velocity of the member under test. This differentiated voltage is then rectified to provide the unidirectional potential necessary for increasing the cathode ray tube grid potential during either the forward or return or both motions of the object under test. In order to prevent any possible leakage currents through the rectification circuits from producing spurious variations in the voltage applied to the grid Z of oscilloscope 2, with consequent screen brightness variations, the rectified voltage is clipped to a constant reference level. After amplification, the resultant positive voltage, which is of a magnitude proportional to the velocity of the member under test, is applied to the grid Z. The result attained is that the intensity of the cathode ray beam is increased just at the time the rate of deflection of the beam increases; hence compensating for the tendency for spot brightness to decrease during the shorter time during which the beam is at any particular point of the screen when the beam is being more rapidly deflected. Uniform brightness of the trace on the oscilloscope screen is thereby obtained.

BRIGHTNESS CONTROL CIRCUIT

A detailed description of a preferred embodiment of the brightness control circuit will be made by reference to Fig. 3. The transducer is designated in block 3. As will be explained in detail later in this specification, it is considered to be so connected that the voltage at its output terminals is at a maximum negative value relative to ground when a vibratory mechanical member under test is in the extreme operated position of its path of motion, and is at a maximum positive value when the mechanical member is in its fully released position. This supposition as to sign is purely for the purpose of

definiteness in description, as it will be evident that the invention will perform in the same manner with merely a difference in switch labeling if these voltage conditions should be reversed. Potentiometer 7 and resistor 9 constitute the output load for the transducer. Potentiometer 7 enables a desired fraction of this output voltage to be applied to the grid of a vacuum tube V_1 to establish class A operating conditions, wherein the voltage variation at the plate of tube V_1 is a replica of the voltage variation at the grid. Tube V_1 functions as an amplifier, and must be capable of linear class A operation over the complete swing of the voltage applied to its grid. The connection of an unbypassed resistor 11 between the cathode of tube V_1 and ground provides bias, grid current limitation, and adequate degenerative feedback to stabilize the operating characteristics of tube V_1 for linear operation. The plate of tube V_1 is connected through the primary winding 14 of a transformer 13 to a source of positive direct-current plate supply potential $B+$. With this arrangement, the signal component of the plate voltage of tube V_1 will be linearly proportional to the transducer output voltage which is applied to the grid of tube V_1 . As is explained in detail below, this voltage is linearly proportional to the instantaneous displacement of the mechanical member under test from its fully released or fully operated position. Hence, the plate voltage of tube V_1 is linearly proportional to displacement of the mechanical member under test, and so has a voltage vs. time characteristic the same as the displacement vs. time characteristic shown in Fig. 2. If the plate current of tube V_1 is i amperes, and the mutual inductance between the primary and secondary windings is M henries, the voltage at terminals 41—45 of the secondary winding 16 will be given by

$$e_2 = M \frac{di}{dt} \quad (1)$$

That is, the secondary voltage is proportional to the rate of change of the alternating-current component of the plate current of tube V_1 . If the alternating-current component of the plate voltage of tube V_1 is e_1 , and the total resistance in the plate circuit, including the dynamic plate resistance of tube V_1 , is designated by R , then

$$e_1 = iR + L \frac{di}{dt} + M \frac{di_2}{dt} \quad (2)$$

where L is the self inductance of the primary winding 14 of the transformer and i_2 is the current in secondary winding 16. Equation 2 can be written as

$$\frac{e_1}{R} = i + \frac{L}{R} \frac{di}{dt} + \frac{M}{R} \frac{di_2}{dt} \quad (3)$$

For virtually any vacuum tube and coupling transformer R will be very large in comparison with either L or M , so that all but the first term of Equation 3 can be ignored, and

$$\frac{e_1}{R} = i \quad (4)$$

Substituting this result in Equation 1, the result is

$$e_2 = \frac{M}{R} \frac{de_1}{dt} \quad (5)$$

In other words, the voltage at the terminals of the secondary winding of the transformer is proportional to the time rate of change of the plate voltage of tube V_1 . Since, as described above, the latter voltage is proportional to the instantaneous displacement of the mechanical member under test, the voltage across the secondary winding of the transformer 13 is proportional to the instantaneous velocity of the mechanical member under test.

Since the polarity of the transducer output voltage changes from maximum positive to maximum negative value as the object under test moves from operated to released position, and from maximum negative to maxi-

mum positive value as the object under test moves from its released to operated position, the time rate of change of this voltage, which is the voltage existing at the secondary terminals 41—45 of transformer 13, will consist of alternate sharp positive and negative pulses as the mechanical member under test continuously vibrates.

Since it is desired to brighten the trace on the cathode ray tube when the mechanical member under test is in motion (regardless of whether it is moving towards its operate or release position), it is necessary to rectify the voltage across the secondary winding of transformer 13. The arrangement comprising rectifiers 15, 17, 19 and 21 and two gang four wiper switch S_1 is included for this purpose. This switch is so constructed that wipers 23, 25, 27 and 29 are each always at the same lettered ones of the four terminals a , b , c and d , associated with each wiper. This is accomplished by mechanical wiper couplings shown schematically by the dashed lines 31, 33 and 35. The terminals b and d associated with wiper 23 are connected together, as are the terminals b and d associated with the wiper 29. Also, the terminals c and d associated with the wiper 25 are connected together, as are the terminals c and d associated with the wiper 27. Resistor 37 constitutes the load on the secondary winding 16 of transformer 13, and is connected at one end to the junction of a connection between terminal b associated with wiper 23 and terminal c associated with wiper 27 and at the other end to the junction of a connection between terminal c associated with wiper 25 and terminal b associated with wiper 29. Rectifiers 15 and 17 are connected together in opposing relation at junction point 39, which in turn is connected to the terminal 41 of the secondary winding 16 of transformer 13. The other terminal of rectifier 15 is connected to wiper 23, and the other terminal of rectifier 17 is connected to wiper 25. Rectifiers 19 and 21 are connected together in opposing relation at junction point 43, which is connected to the other terminal 45 of the secondary winding 16 of transformer 13. The other terminal of rectifier 19 is connected to wiper 27, and the other terminal of rectifier 21 is connected to wiper 29. With this arrangement, when all wipers of switch S_1 are connected to their associated terminals lettered " a ," the secondary winding of transformer 13 is completely disconnected from load resistor 37 and no voltage appears across that resistor. When the wipers of switch S_1 are all rotated to contact their terminals lettered " b ," current will flow through load resistor 37 when the terminal 41 of the winding 16 is positive. The current path will be from terminal 41 through rectifier 15, which is arranged in its conducting direction for a positive potential at terminal 41, through wiper 23 and the terminal b associated with that wiper, through load resistor 37, through the terminal b associated with wiper 29, through wiper 29, through rectifier 21 to terminal 43, and thence back to the other terminal 45 of winding 16. Since rectifier 17 is arranged in its conducting direction for only a negative potential at terminal 41, and since the terminal b associated with wiper 25 connected to rectifier 17 is isolated from resistor 37, only minute current can flow through resistor 37 with the wipers contacting their b terminals when the voltage at terminal 41 is negative. As stated above, the output of the transducer designated in block 3 is assumed to be negative when the vibrating mechanical member under test is fully operated and positive when the operating member is fully released. Since the plate voltage of vacuum tube V_1 is reversed in phase from the voltage applied to its grid, which is the well known characteristic of vacuum tubes, the alternating-current component of the plate voltage of tube V_1 is positive when the mechanical member under test is operated and is negative when the mechanical member is released. Assuming that the primary and secondary windings of the transformer 13 are wound in the same sense, so that no phase reversal exists between the voltage at the primary

and secondary windings, the potential at terminal 41 of the secondary winding 16 of transformer 13, which is the rate of change of the plate voltage of tube V_1 , will be positive when the mechanical member moves from released to operated position and will be negative when it moves from operated to released position. From this, it follows that with the wipers of switch S_1 contacting their "b" terminals voltage will only appear across resistor 37 when the mechanical member under test moves from its released to its operated position.

In order to make the voltage across the resistor 37 responsive only to motion of the mechanical member under test from operated to released position, when terminal 41 is negative, the wipers of switch S_1 are moved to contact their terminals numbered c. In this condition the rectifier 15, which only conducts when the potential at terminal 41 is positive, will be isolated from resistor 37 since its opposing terminal, which will be wiper contact c, is isolated from resistor 37. When the potential at terminal 41 is negative, and so terminal 39 also, terminal 45 will be positive. Current flow will therefore be from terminal 45 to terminal 43, through rectifier 19, which is in the conducting direction for a positive potential at terminal 43, through wiper 27 and its contact c, through resistor 37 to terminal c of wiper 25, through wiper 25, through rectifier 17, to terminal 39 and thence to terminal 41.

In the event it is desired to brighten the cathode ray screen during both the operate and release motions of the mechanical member under test, it is only necessary to operate switch S_1 so its wipers contact their terminals d. This, in effect, is a full wave rectifier connection. Since the terminals b and d associated with wiper 23 are connected together, and since this is also true of wiper 29, the current flow through resistor 37 when terminal 41 is positive traverses the same path as described above when the wipers are connected to their terminals lettered b. Since terminals c and d associated with wiper 25 are connected together, and since this is also true of wiper 27, the current flow through resistor 37 when terminal 41 is negative traverses the same path as was described above when the wipers were connected to their terminals numbered c. It will be noted that at all times current flow through resistor 37 is in the same direction, which in Fig. 3 is from left to right. The result is that the left-hand terminal of resistor 37 is always at a more positive potential than the right-hand terminal. Accordingly, by grounding the left-hand terminal of resistor 37 and connecting the right-hand terminal via conductor 47 to the grid of vacuum tube V_2 , the grid of vacuum tube V_2 is supplied with a potential which is always negative with respect to ground and which is of a magnitude corresponding to the velocity of the mechanical member under test. If the rectifiers 15, 17, 19 and 21 should have appreciable reverse condition current, as would be the case if crystals rather than vacuum tube diodes are utilized, provision must be made to prevent the appearance at the grid of vacuum tube V_2 of the resultant spurious positive potentials which would adversely affect control of the brightness of the oscilloscope 2. This is accomplished by connecting a rectifier 49 between the grid of tube V_2 and ground, poled so that it is only conductive when the potential at the grid of tube V_2 is positive. Hence, rectifier 49 effectively shunts any reverse conduction currents to ground. Tube V_2 functions to amplify and to clip the tops of the negative pulses applied to its grid, so that its plate voltage will not exceed a substantially constant positive value when the mechanical member under test is in rapid motion. This plate voltage is utilized to modulate the grid voltage of the cathode ray oscilloscope 2. A resistor 51 connected between the cathode of tube V_2 and ground provides a small amount of degenerative feedback which tends to stabilize the operation of tube V_2 . Positive direct-current plate potential for tube V_2 is provided by connecting its plate through

a load resistor 53 to positive direct-current source B+. An auxiliary resistor 55 is connected between ground and the plate of tube V_2 , and functions as a tap-off resistor for potentiometer arm 57. Potentiometer arm 57 can be adjusted to tap any desired portion of the output voltage appearing across resistor 55. Potentiometer arm 57 is connected to the grid Z of the cathode ray oscilloscope 2. The voltage applied to grid Z by potentiometer 57 is positive, by virtue of the fact that the potential at the grid of tube V_2 is negative, and as is commonly understood, the plate potential of tube V_2 is phase inverted with reference to the grid voltage. As a result, whenever a potential exists at the grid of tube V_2 , as will be the case whenever a potential exists across load resistor 37, the potential of the grid Z of the cathode ray oscilloscope 2 is increased, the beam intensity is thereby increased, and the brightness of the trace on the cathode ray screen is increased. As stated above, the magnitude of the voltage existing across the secondary winding 16 of the transformer 13 is linearly proportional to the instantaneous velocity of the mechanical member under test. In addition, the rectifying circuit described above does not affect the magnitude of the voltage applied to it. Hence, the voltage at the grid of tube V_2 will be linearly proportional to the instantaneous velocity of the mechanical member under test. The voltage B+, and the size of the cathode resistor 51 and plate resistor 53 of tube V_2 are chosen so that tube V_2 operates as a linear class A amplifier for negative grid voltages less than that which cuts V_2 off, making its output voltage a true replica of the wave shape of the input voltage up to a minimum value. Accordingly, the degree to which the beam intensity of the cathode ray oscilloscope 2 is increased will be linearly proportional to the velocity of the mechanical member under test up to a high velocity beyond which the beam intensity remains constant. This is the desired condition for avoiding excessive brightness of the screen of the cathode ray oscilloscope at the points corresponding to the rest positions of the member under test.

The switch S_1 is included in Fig. 3 and in this specification because it affords the added convenience of being able to select which portion of the complete operating cycle of the mechanical member under test is to be observed. From the above description it will be evident that when switch S_1 is operated so its wipers contact their associated terminals lettered "a," no beam brightness control is effected. When switch S_1 is operated so the wipers contact their "b" terminals, the trace on the oscilloscope screen will be brightened when the mechanical member under test moves from its released to its operated position. When switch S_1 is operated so the wipers contact their "c" terminals, the trace on the oscilloscope screen will be brightened when the mechanical member moves from its operated to released position. Finally, when switch S_1 is operated so the wipers contact their "d" terminals, the trace will be brightened whichever way the member moves.

If it should be desired simply to obtain adequate brightness control whenever the member is in motion, with no selectivity as to direction of motion, the switch S_1 may be dispensed with, and the terminals of rectifiers 15 and 19 shown in Fig. 3 to be connected to wipers 23 and 27, respectively, would be directly connected together, and the terminals of rectifiers 17 and 21 shown connected to wipers 25 and 29, respectively, would be directly connected together. Resistor 37 would then be connected between the connected terminals of rectifiers 15 and 19 and the connected terminals of rectifiers 17 and 21. This arrangement will provide a simple full wave rectifier.

While the differentiating circuit described by reference to Fig. 3 comprised a transformer 13, the reason being that this arrangement provided the high degree of linearity desired, it will be evident to those skilled in the art that a capacitive differentiating circuit, of the well known

low time constant type, might be suitable for replacing transformer 13 as the differentiating means.

It is further pointed out that the reference made in the above description and circuit drawing of the brightness control circuit to a transducer and a mechanical member being tested was purely for the purpose of definiteness in describing the application of the invention to a specific testing arrangement. As is evident from the description, all that is necessary for proper application of the invention is that there be applied to the grid of tube V_1 an oscillatory voltage, the instantaneous magnitude of which is to control the deflection of the electron beam of a cathode ray tube, having relatively long quiescent intervals in its oscillatory cycles.

While a multitude of suitable values of circuit components, electron tube types and source potentials would provide suitable operation of the brightness control circuit when chosen in accordance with the description of its construction and operation presented above, the following values and types have been found to provide highly satisfactory operation:

Resistors:

7	-----megohms--	1
9	-----ohms--	56000
11	-----do	1000
37	-----megohms--	0.1
51	-----ohms--	5000
53	-----do	56000
55	-----megohms--	0.2

Rectifiers:

15, 17, 19, 21 and 49—all type 1N43 varistors.

Tubes:

V_1 —type 6SN7, with the two plates connected together, the two cathodes connected together, and the two grids connected together.

V_2 —type 12AU7, using only 1 of the 2 triodes in this type.

Voltage source $B+$: +165 volts.

TRANSDUCER

A detailed description of the improved transducer will now be given. Referring to Fig. 4, the transducer is shown connected to respond to the instantaneous position of a vibrating mechanical member which, for definiteness, is shown as a relay armature 61 having a core 63 and an operating winding 65. The armature is caused to repetitively vibrate between its released position, shown by the solid lines in Fig. 4 and its fully operated position, shown by the dotted lines. Any of a multitude of available suitable means for causing a relay armature to repetitively release and operate, such as are well known to those skilled in the art, may be utilized for this purpose. One such means, shown schematically in Fig. 4, is to energize the relay operating winding 65 from a square wave generator designated in block 67 which produces square voltage pulses interspersed at regular intervals by zero voltage, the pulses recurring at a sufficient rate to cause the armature to continually vibrate at a desired rate. Since such generators are well known in the art, further description would be superfluous. The relay core 63, which is in electrical contact with armature 61, is connected to ground potential. Hence, armature 61 is effectively grounded. A conducting metal electrode 69, serving as a capacitive probe, is mounted on an insulating mechanical support 71 in close proximity to the armature when the armature is in fully released position. The probe 69 is connected by a conductor 73 to a terminal 74. The probe 69 is thus capacitively coupled to armature 61, and serves as the fixed electrode of a probe condenser of which the armature 61 forms the movable electrode. The electrode spacing of the probe condenser thus formed increases in substantially linear relationship with the position of armature 61 as the armature moves from its fully released to its fully operated position, and de-

creases substantially linearly as the armature moves from its fully operated to its fully released position. The reason the relationship is linear is that the total angle through which a practical relay armature rotates between its released and operated positions is less than about 8 degrees, so that the displacement of the tip of the armature from the core is linearly proportional to armature angular rotation within a maximum error of less than 1 percent.

The control grid 75 of a vacuum tube V_3 is connected to the terminal 74 through the parallel combination of condenser 78 and resistor 79, this combination functioning to provide self bias of the control grid 75 of tube V_3 . An oscillatory tank circuit comprising the parallel combination of condenser 81 and inductor 83 is connected between terminal 74 and ground. Tube V_3 has a cathode 77 which is connected to a tap on the inductor 83 at a point nearer the grounded terminal of that inductor than the terminal connected to condenser 81. Tube V_3 also has a heater 85, and a screen grid 87 which is provided with positive potential from direct-current source $B+$ through grid current-limiting resistor 89. Connected between screen grid 87 and ground is a relatively large direct-current blocking condenser 88 which serves to isolate source $B+$ from the tank circuit comprising condenser 81 and inductor 83, and yet effectively provides an alternating-current ground for grid 87. Tube V_3 has a suppressor grid 90 which is grounded, this grid serving to electrostatically shield the plate 91 of tube V_3 from the screen grid 87 and control grid 75. Plate 91 is provided with positive potential via connection to source $B+$ through the parallel combination of an inductor 93 and condenser 95.

With this arrangement, tube V_3 and the circuits thus far described form an electron coupled oscillator of a type well known in the art. The cathode, control grid and screen grid act together as a conventional Hartley type triode oscillator, the screen grid 87 behaving as a virtual plate with respect to the control grid 75. Since the screen grid and control grid are connected to opposite ends of the tank circuit comprising condenser 81 and inductor 83 with respect to the cathode 77, feedback between the control grid and screen grid is of the proper phase displacement to sustain oscillation. The amount of feedback, and so the amplitude of oscillation, is determined by the proportion of inductor 83 which is connected between ground and cathode 77, this being set by the point of inductor 83 to which cathode 77 is connected. Oscillation is sustained even though a relatively small portion of the electrons emitted by cathode 85 is intercepted by the screen grid 87, most continuing on to plate 91. The frequency of oscillation is determined by the resonant frequency of the parallel combination of condenser 81, inductor 83 and the probe condenser which shunts condenser 81. The result is that, even though screen grid 87 is isolated from plate 91 by grounded suppressor grid 89, the plate current is modulated by the oscillation taking place in the screen grid and control grid circuits. This achieves the advantages of a buffer amplifier, whereby any load coupled in the plate circuit is isolated from the oscillator, without the necessity of using a separate amplifier. The frequency of this electron coupled oscillator, which otherwise would be constant, is varied in accordance with the varying capacitance of the probe condenser. For example, as armature 61 moves from its released to its operated position the capacitance of the probe condenser comprising probe electrode 69 and armature 61 decreases because of the increased spacing between these electrodes. This decreased capacitance reduces the net capacitance shunting inductor 83, and the resonant frequency of the oscillator comprising tube V_3 increases. The reverse occurs when armature 61 moves from its operated to its released position. Consequently, a frequency modulated alternating-current potential appears at the plate 91 of tube V_3 . Condenser 97 shunts source $B+$, and acts as a plate by-pass condenser which

provides a definite alternating-current ground connection for the inductor 93 and condenser 95 connected to plate 91. The parallel combination of inductor 93 and condenser 95 has a resonant frequency of maximum response which differs from the oscillatory frequency determined by the tank circuit of tube V_3 shunted by the probe condenser for all positions of the armature 61. For definiteness of description, it will be assumed that the resonant frequency of inductor 93 and condenser 95 in parallel is higher than the highest resonant frequency produced in the tank circuit of tube V_3 . The resultant voltage which appears across inductor 93 and condenser 95 is applied through direct-current blocking condenser 99 to the plate of a diode 101 having a cathode which is grounded. It will be apparent to those skilled in the art that the arrangement thus described comprising inductor 93, condenser 95, blocking condenser 99 and diode 101 constitutes a discriminator circuit for recovering a voltage of a magnitude which varies in accordance with the frequency modulation of the alternating-current potential at plate 91 of tube V_3 . This can clearly be seen by reference to Fig. 5, which is a graph of the voltage appearing across the parallel combination of inductor 93 and condenser 95, and so across the discriminator circuit, plotted against frequency. The curve shown is the resonance characteristic of the parallel combination of inductor 93 and condenser 95, and so too of the complete discriminator circuit. As seen, the voltage output of the discriminator is a maximum at a particular resonant frequency F_d . The frequency F_0 shown on the graph is the middle of the range of resonant frequencies of the oscillator comprising tube V_3 which are produced as armature 61 vibrates between its operated and released positions. The dotted lines to the right and left of F_0 represent the frequencies existing in the tank circuit of tube V_3 when armature 61 is in its full operated and released positions, respectively. To give an indication of the magnitudes involved in one embodiment of the transducer which was found to give satisfactory results, the frequency F_d was about 100 megacycles, the frequency F_0 was about 97 megacycles, and the frequency shift about F_0 was from 96 to 98 megacycles. There are two reasons for using these relatively high frequencies. The first is due to the fact that the maximum capacitance of the probe condenser will only be a few micro-microfarads. In order for the variation of such a small capacitance to substantially shift the frequency of the tank circuit of tube V_3 it is necessary that the fixed capacitance of the tank circuit be comparably small. This necessitates a high resonant frequency F_0 . The second reason is to obtain a high degree of resolution of the armature motion as portrayed on the oscilloscope. The armature bounce at the extremes of its operating path produces transients having displacement frequency components of 100 kilocycles and higher. To enable the detector to efficiently respond to such a high frequency modulating component of the modulated signal applied to it, and yet to filter out the carrier frequency component, the carrier frequency F_d must be a considerable multiple of the modulating frequency. The chosen value of F_d has been found to provide this high detection efficiency.

If inductor 93 has substantial resistance, the resonance curve of Fig. 5 will have a flattened peak and closely linear slopes on either sides of the peak at F_0 . In any event, by adding shunt resistance across inductor 93, as great a degree of linearity of the slopes as desired over the range to be used can be attained. In addition, by making the varying capacitance of the capacitive probe small compared to the total fixed capacitance shunting inductor 83 in the tank circuit, the total variation in frequency of the tank circuit can all be confined to a small portion of the resonance curve shown in Fig. 5. The capacitance of the probe condenser is the sum of a fixed capacitance, corresponding to the fully operated position of armature 61, and a varying capacitance which is zero

when the armature is fully operated and a maximum when the armature is fully released. Hence, the fixed capacitance shunting inductor 83 is the sum of the capacitance of tank circuit condenser 81 and the fixed capacitance component of the total capacitance of the probe condenser. Condenser 81 may be chosen with enough capacitance so the varying capacitance of the probe condenser is a small part of the total fixed capacitance shunting inductor 83. Also, placing probe 69 further from the fully released position of armature 61 makes the varying capacitance a smaller part of the total capacitance of the probe condenser.

The range of amplitude variation of the voltage across the parallel combination of inductor 93 and capacitor 95 is shown in Fig. 5 as E_0 , and extends between the output voltages corresponding to the frequencies at the extremes of the resonant frequency range of the oscillator comprising tube V_3 . Accordingly, the combination of inductor 93 and condenser 95 functions to convert the frequency modulated voltage at the plate 91 of tube V_3 to an amplitude modulated voltage, the amplitude modulation being linearly proportional to the frequency modulation. Since only the relatively slowly varying modulating envelope of the rapidly oscillating modulated voltage existing across the parallel combination of inductor 93 and condenser 95 is desired, a conventional AM detector 94 is utilized only to recover the envelope voltage. This detector includes the diode 101, which recovers the negative half of the composite modulated wave form at its plate. The resistor 103 is connected at one end to the plate of diode 101 and at the other end to one terminal of condenser 105, the other terminal of condenser 105 being grounded. This combination of resistor 103 and condenser 105 functions as a filter which removes the high frequency carrier component of the potential existing at the plate of diode 101 and provides at its output across condenser 105 only the desired modulating component of the potential applied to the plate of diode 101. Since the complete discriminator circuit operates in a linear manner, as described above, the instantaneous value of the detected output voltage of detector 94 is linearly proportional to the instantaneous variation of the frequency of the oscillator comprising tube V_3 from its quiescent value at the center of the range of frequencies produced by vibration of armature 61. By proper choice of the circuit components of the tank circuit of tube V_3 , as will be described in detail below, it is possible to achieve the condition whereby the frequency variation of the oscillator comprising tube V_3 is linearly proportional to the separation of the electrodes of the probe condenser comprising armature 61 and metal probe 69. Consequently, the output voltage of detector 94 is linearly proportional at every instant to the displacement of armature 61. In Fig. 6 there is shown a graph of this voltage with respect to the displacement of armature 61 from its fully operated position adjacent the relay core. Specific values of voltage and armature displacement were included on this graph in order to give an indication of the order of magnitudes involved. These values were obtained by actual tests on a commercial relay. As seen from Fig. 6, and as was to be expected in view of the connection of diode 101 to detect only the negative portions of the wave form applied to its plate, the variation of the detected voltage at the output of detector 94 is always centered about a negative average potential exceeding the maximum voltage variation. This is as desired in order that this voltage should be suitable for application to the grid of a vacuum tube V_4 functioning as a cathode follower. Tube V_4 and the associated circuit now to be described function as a zero setting arrangement which eliminates the relatively large average direct-current component of the output voltage of detector 94. The reason this component must be eliminated follows from the fact that since the magni-

tude of the output voltage of the detector 94 is linearly proportional to the displacement of relay armature 61, the detector output voltage varies with time in the same manner as armature displacement does. The latter variation is shown in the graph of Fig. 2, and is seen to approximate a square wave. Since it is well known that capacitively coupled circuits substantially distort square wave signals, linear amplification of the detector output voltage, which is necessary in order that its magnitude will be adequate for controlling the cathode ray oscilloscope, can only be accomplished by a direct-current coupled amplifier. Such an amplifier would be immediately overloaded, and so would distort the wave shape of the detector output voltage, if the direct-current bias component of the output voltage of detector 94 was not eliminated prior to application to the amplifier.

Tube V_4 has a plate supplied with positive potential from direct-current source $B+$, and has a cathode connected through a resistor 107 to a source of negative potential $-E$ which establishes proper cathode bias for linear operation of tube V_4 with a plate voltage $B+$ and the relatively large negative voltage applied to its grid from detector 94. Resistor 109 connected between the grid of tube V_4 and ground provides a path for grid leakage current. The grid of tube V_4 is also connected to the junction of resistor 103 and condenser 105, so that the output voltage of detector 94 is applied to the grid of tube V_4 . Also connected to the cathode of tube V_4 is a rheostat 111 in series with a fixed resistor 113 which is connected at its other end to the source of positive potential $B+$. The output of this zero setting circuit is taken at terminal 115, and is a voltage varying with armature displacement in the same manner as shown in Fig. 6, but between equal positive and negative voltage extremes. With reference to the values shown in Fig. 6, the voltage variation at point 115 would be from plus 1 volt to minus 1 volt. The manner in which this arrangement attains this result can be understood by reference to the basic theory of cathode followers, such as is given, for example, on pages 308-311 of the textbook "Radio Engineering" by F. E. Terman, third edition. As explained therein, the voltage existing at the cathode of tube V_4 will be of the same form as the voltage applied at the grid but slightly smaller in magnitude. Also, looking back from the terminal of potentiometer 111 connected to the cathode of tube V_4 , the cathode voltage will appear to be in series with a small apparent resistance comprising resistor 107 in parallel with a resistance very nearly equal to the reciprocal of the dynamic transconductance of tube V_4 . Assuming, for example, that the voltage at the cathode of tube V_4 varies between minus 7 and minus 5 volts, in response to a voltage variation of minus 8 to minus 6 volts at the grid, the overall equivalent circuit of the cathode follower tube V_4 and the circuits connected to its cathode can be represented as shown in Fig. 7. In this figure, point P represents output terminal 115 and is at a potential V . The resistance " r " represents the small apparent resistance in series with the cathode potential. Resistance R_1 represents the resistance of the portion of rheostat 111 not short-circuited by the rheostat brush, and resistance R_2 represents resistor 113. The battery " e " represents the cathode potential which varies between minus 7 and minus 5 volts. This is equivalent to an alternating voltage having an amplitude of 1 volt, varying about a constant voltage level of minus 6 volts. Hence, considering the potential of battery " e " to be minus 6 volts, to balance out the direct-current component of the potential at point P, which is the object of the zero setting circuit, it is only necessary that the voltage V in the equation

$$V = (B+) - \left(\frac{1}{1 + \frac{R_1}{R_2} + \frac{\gamma}{R_2}} \right) [6 + (B+)] \quad (6)$$

be equal to zero. Since the value of R_1 can be adjusted by means of rheostat 111, the rheostat can be adjusted until V does equal zero.

The potential variation at point 115 must be amplified to a magnitude sufficient for horizontally deflecting the cathode ray beam of an oscilloscope over substantially the entire width of the oscilloscope screen. To accomplish this amplification, point 115 is connected to a direct-current amplifier designated in block 117. The output of the complete transducer, which is the requisite deflecting potential, thereby appears at the output terminal 119 of this amplifier. The only particular requirement placed on the direct-current amplifier in block 117 is that it be capable of highly stable operation in order that no distortion of the input voltage at point 115 be introduced. Many types of suitable direct-current amplifiers are known and are familiar to those skilled in the art. A specific example of a suitable amplifier is shown in Fig. 6-60C on page 335 of the text "Radio Engineering" by F. E. Terman, third edition, and is described in that text on pages 335-336. Accordingly, a detailed description of the direct-current amplifier shown in block 117 would be superfluous and is not included in this specification.

With the configuration shown in Fig. 4, whereby the capacitance of the probe condenser comprising probe 69 and armature 61 is a maximum when armature 61 is released and minimum when armature 61 is fully operated, and detector 94 detects only the negative half of the amplitude modulated signal at its plate and operates on the lower frequency portion of the curve shown in Fig. 5, the potential at point 115 will be most negative when armature 61 is fully operated and most positive when armature 61 is released. If the direct-current amplifier in block 117 has an odd number of stages of amplification, its output will be a phase reversed replica of the potential at point 115. If it has an even number of stages, its output will be of the same phase as the potential at point 115. In either case, it is thus ascertained when the output of the direct-current amplifier is most positive and when it is most negative, in relation to the operate and release positions of armature 61.

When the transducer output is to be displayed on an oscilloscope, the output terminal 119 of the direct-current amplifier 117 is connected to active terminal X of the horizontal deflection electrodes H-H of oscilloscope 2, the other terminal of these electrodes being grounded as shown in Fig. 4. It is assumed that oscilloscope 2 is so disposed that a positive potential at terminal X causes the spot on the oscilloscope screen to move toward the right-hand edge of the screen, as seen facing the screen. Accordingly, if the output of the direct-current amplifier is most positive when armature 61 is fully released, the spot on the oscilloscope screen will be deflected from the left-hand to the right portion of the screen when armature 61 moves from its fully operated to its fully released position, and reverse when armature 61 moves back to its operated position. This is the preferred mode of operation, and for definiteness of description is the one assumed to exist in the remainder of this specification. To attain this mode of operation in the case where the output of the direct-current amplifier is most positive when armature 61 is fully operated, it is only necessary to interchange the connection of horizontal deflection electrodes H-H, so that terminal X is grounded and the formerly grounded terminal is connected to output terminal 119 of the direct-current amplifier 117.

Inasmuch as it is well known that the operation of vacuum tubes requires application of suitable potential to the cathode heaters of such tubes, the manner of accomplishing this also being well known standard practice in the art, no heaters or heater circuits for any of the tubes in Fig. 4 have been shown with the exception of tube V_3 . The reason for this is that the cathodes of

all other tubes are returned effectively to an alternating-current ground potential, while, as described above, the operation of tube V_3 as an electron coupled oscillator requires connection of its cathode to a point on tank circuit inductor 83. Since high frequency oscillatory current passes through this inductor, cathode 85 of tube V_3 is at a rapidly oscillating non-zero alternating-current potential. Due to the proximity of the heater 85 to the cathode 77, this oscillating potential will be capacitively coupled into the heater circuit. Provision must, therefore, be made to prevent it from flowing to the common source of heater potential designated in block 129, and through it back to the heaters of other tubes in the circuit with consequent variation of the alternating-current cathode potentials of that tube. This is done by connecting the parallel combination of a choke and resistor in each heater lead of tube V_3 . Inductor 119 and resistor 121 form one such combination and inductor 123 and resistor 125 form the twin of that combination for insertion in each of the two leads of heater 85. Since inductors 119 and 123 inevitably possess some distributed capacitance through which some of the alternating-current potential of heater 85 could escape, condensers 127 and 128 are respectively connected to the terminal of each of the parallel resistor and choke combinations to provide an effective high frequency alternating-current ground for each of them. The heater supply designated generally in block 129 is then simply connected to the junction points of condensers 127 and 128 with the choke and resistor combinations to which those condensers are respectively connected.

While circuits resembling the transducer thus far described have been known, it has heretofore been considered impossible to attain a high degree of linearity of transducer output voltage variation with electrode separation of the probe condenser. The reason for this is that the mathematical relationship between the spacing between the electrodes of a condenser and the resonant frequency of the oscillatory circuit formed by the parallel combination of the condenser and an inductor is not a linear one. This is a consequence of the fact that the resonant frequency of the parallel combination of a condenser and an inductor is inversely proportional to the square root of the product of the capacitance and inductance, and so is itself a non-linear function of the value of the capacitance. Therefore, to achieve linear operation, transducers have been devised utilizing twin capacitive probes, one disposed on either side of the vibratory mechanical member under test. Having thus made oppositely varying capacitances available, a push-pull type arrangement which balances out the non-linear performance of each individual probe can be established. The article "Push-pull frequency modulated circuit and its application to vibratory systems," by H. Badmaieff, appearing on page 37 of the January 1946 issue of the Journal of the Society of Motion Picture Engineers, describes such an arrangement.

However, in many cases it is mechanically very difficult and sometimes impossible to dispose capacitive probes on both sides of a vibratory mechanical member under test. This is particularly true in the case of many commercial types of multicontact relays, where the armature is exposed on one side but is closely adjacent to contact operating mechanisms on the other side. By careful analysis, which will now be presented, it has been found possible to choose such values for the circuit components of the improved transducer described above and depicted in Fig. 4 that a linear variation of output voltage with separation of the electrodes of the probe condenser is obtained with use of only a single capacitive probe. This transducer, therefore, possesses a novel and highly useful attribute not heretofore considered attainable by those skilled in the art.

Referring to Fig. 4, and considering first the plate cir-

cuit of tube V_3 , the amplitude of the oscillatory current passing from the plate of tube V_3 remains very closely constant even though its frequency is changing in accordance with the varying capacitance of the probe condenser comprising armature 61 and metal probe 69. The reason is that the amplitude of oscillation is determined by the fixed characteristics of tube V_4 , the resistive losses in its oscillatory tank circuit, and its grid bias. These remain substantially constant when the frequency of the oscillatory tank circuit is varied over a relatively small range. The range is small because the variation of the capacitance of the probe condenser is small compared to the capacitance of tank circuit condenser 81. Let the impedance of the discriminator circuit connected to the plate of tube V_3 , which is the impedance of the parallel combination of inductor 93 and condenser 95, be denoted Z . Also, let the alternating-current component of the plate current of tube V_3 be represented by I_0 . Then the alternating-current voltage across the discriminator circuit impedance Z will be given by

$$E = I_0 Z \quad (7)$$

As the oscillatory frequency changes in response to the motion of the armature 61, Z , and therefore E , change in the above equation while I_0 remains constant.

Let

$$f = \frac{W}{2\pi} = \text{oscillatory frequency}$$

$$f_2 = \frac{W_2}{2\pi} = \text{resonant frequency of the impedance } Z, \text{ which is also the resonant frequency of the discriminator circuit.}$$

$$Y = 1 - \frac{f^2}{f_2^2}$$

L_2 = inductance of inductor 93; and

R_2 = resistance across the terminals of inductor 93 and condenser 95. This is due to the resistance of inductor 93 and of the leads connecting inductor 93 to condenser 95.

Also

$Q = W_2 L_2 / R_2$, Q being the figure of merit of inductor 93 at the frequency f_2 .

Then,

$$Z = \frac{W L_2 Q}{\sqrt{Q^2 Y^2 + 1}} \quad (8)$$

At resonance, when $f = f_2$, Z has a maximum value denoted by $Z_{\max}$, and given by

$$Z_{\max} = W L_2 Q \quad (9)$$

When Z is a maximum, E is also a maximum, as seen from Equation 7. Denoting the maximum value of E as $E_{\max}$, and providing W/W_2 is near unity, from Equations 7 and 9 we get

$$\frac{E}{E_{\max}} = \frac{Z}{Z_{\max}} = \frac{1}{\sqrt{Q^2 Y^2 + 1}} \quad (10)$$

Now considering the control grid circuit of tube V_3 , which circuit determines the oscillatory frequency, the probe condenser comprising metal probe 69 and armature 61 is closely equivalent to a parallel plate condenser. As is well known, the capacitance of such a condenser is inversely proportional to the plate separation.

Let

d = plate separation of the probe condenser with armature 61 in any instantaneous position.

d_1 = plate separation of the probe condenser which results in an oscillatory frequency f which is equal to the resonant frequency f_2 of the impedance Z .

$$x = \frac{d}{d_1}$$

Also, let

C_1 =capacitance of the varying capacitance component of the total capacitance of the probe condenser when the plate separation is d_1 .

C_p =capacitance of the varying capacitance component of the total capacitance of the probe condenser when the plate separation is d .

C_0 =total of the capacitance of tank condenser 81 and the fixed capacitance component of the total capacitance of the probe condenser.

$C_1/C_0=K$, a constant

Then

$$\frac{C_p}{C_1} = \frac{d_1}{d}, C_p = C_1 \frac{d_1}{d} \cdot \frac{C_1}{x}$$

Hence the total capacitance shunting inductance L_2 is given by

$$C_0 + C_p = C_0 + \frac{C_1}{x}$$

The oscillatory frequency " f " is therefore given by the equation

$$(2\pi f)^2 = W^2 = \frac{1}{L_1(C_0 + C_p)} = \frac{1}{L_1\left(C_0 + \frac{C_1}{x}\right)} = \frac{1}{L_1 C_0 \left(1 + \frac{K}{x}\right)} \quad (11)$$

where L_1 =inductance of tank circuit inductor 83. From Equation 11, and since at resonant frequency f_2 of impedance Z the value of x is unity, we get

$$W_2^2 = \frac{1}{L_1 C_0 (1 + K)} \quad (12)$$

From Equations 11 and 12, it follows that

$$\frac{W^2}{W_2^2} = \frac{1 + K}{1 + K/x} \quad (13)$$

Hence

$$Y = 1 - \frac{W^2}{W_2^2} = 1 - \frac{x + Kx}{K + x} = \frac{1 - x}{1 + \frac{x}{K}} \quad (14)$$

This expression for Y may be substituted in Equation 10, giving

$$\frac{E}{E_{\max}} = \frac{1}{\sqrt{1 + Q^2 \left(\frac{1 - x}{1 + x/K}\right)^2}} \quad (15)$$

Since the varying capacitance of the probe condenser is very small compared to the total of the fixed capacitance of the probe condenser and the capacitance of tank condenser 81, K is very much less than 1. Also, by placing probe 69 sufficiently far from the fully released position of armature 61, K can be made as small as desired in comparison with the minimum value of x . Hence the value of x/K is very much greater than 1. Making this justified simplification of Equation 15, it thereby becomes

$$\frac{E}{E_{\max}} = \frac{1}{\sqrt{1 + K^2 Q^2 \left(\frac{1 - x}{x}\right)^2}} \quad (16)$$

Equation 16 gives the voltage E applied to the detector 94 as a function of the product $(KQ)^2$ and the plate separation of the probe condenser. Once all circuit values have been selected, $E_{\max}$ is a constant and x is linearly proportional to plate separation " d " of the probe condenser, because the plate separation d_1 which will produce an oscillatory frequency equal to the resonant frequency f_2 of the plate circuit impedance Z is a constant. Hence, if $E/E_{\max}$ were linearly proportional to the value of x a perfectly linear transducer performance would result.

While Equation 16 shows that no such linear relationship exists, by plotting graphs of $E/E_{\max}$ against various values of x , each graph for a particular value of $(KQ)^2$, it is possible to find a value of $(KQ)^2$ over which the relationship is very closely linear over a maximum range of variation of x . This value is found to be

$$(KQ)^2 = 2 \quad (17)$$

The center of the linear range is at $x=1/2$, and the total range is from nearly zero to about $x=0.7$. This compares highly favorably with the results attained with the twin probe push-pull transducers heretofore known.

The quantity Q is the figure of merit of inductor 93 at the resonant frequency of the discriminator circuit, and can be selected by choosing an inductor having the requisite resistance and inductance at that frequency. The quantity K is a ratio. The numerator is the capacitance of the varying capacitance component of the total capacitance of the probe condenser comprising capacitive probe 69 and relay armature 61, at which the oscillator comprising tube V_3 oscillates at the resonant frequency of the discriminator circuit connected to the plate of tube V_3 . The denominator is the total of the capacitance of tank circuit condenser 81 and the capacitance of the fixed minimum capacitance component of the total capacitance of the probe condenser. Hence, the value of K can be selected by choosing the appropriate size condenser 81. Accordingly, a single capacitive probe transducer of the type described can be constructed in accordance with Equation 17 above, and will operate linearly over a range of probe condenser electrode separation comparable to that of the double capacitive probe transducers known to the art. The tremendous mechanical advantages thus afforded will be immediately recognized by those familiar with the testing of vibrating mechanical members in close proximity to associated equipment.

While a multitude of suitable values of circuit components, electron tube types and source potentials would provide suitable operation of the transducer when chosen in accordance with the description of its construction and operation presented above, the following values and types have been found to provide highly satisfactory operation:

Resistors

Number:	Resistance in ohms
89-----	47,000
103-----	47,000
107-----	10,000
109-----	1,000,000
111-----	25,000
113-----	100,000
121-----	47,000
125-----	47,000

Condensers

Number:	Capacitance in micromicrofarads
77-----	25
81-----	5
88-----	500
95-----	5
97-----	500
99-----	10
105-----	25
127-----	500
128-----	500

Inductors:

- Nos. 83 and 93 are National type AR-5 coils, of approximately 0.2 microhenry inductance each.
 No. 119 is a single layer coil of No. 24 enameled wire wound on resistor 121.
 No. 123 is a single layer coil of No. 24 enameled wire wound on resistor 125.

Tubes:

V₃ is a type 6AU6.

101 is a type 6AL5, using only one of the two diodes in this type.

V₄ is a type 12AU7, using only one of the two triodes in this type.

Voltage sources:

(B+) +165 volts.

E -48 volts.

DYNAMIC RELAY GAUGING

As applied to dynamic relay gauging, by which is meant testing the operation of the contacts of a relay in relation to relay armature position while the armature is continuously vibrating between operate and release positions, the transducer and beam brightening circuit are utilized together as shown in the block diagram of Fig. 8. The output of the transducer, which is designated in block 3, is applied to the active terminal X of the horizontal deflection electrodes of the cathode ray oscilloscope designated in block 2, so that the displacement of the spot on the oscilloscope screen is linearly proportional to the position of the relay armature relative to its operated position. The relay armature 61 is in electrical contact with the grounded relay core 63. The transducer is responsive to the armature position via its connection to the capacitive probe designated schematically at 69. By placing an insulating shim of accurately known thickness on the core face opposite the armature, and then causing the armature to continuously vibrate by any suitable means, the extreme left-hand end of the line produced on the oscilloscope screen when the armature continuously vibrates marks the position of the armature when in contact with the shim. When the shim is removed and the armature vibrates, the extreme left-hand end of the line on the screen marks the fully operated position of the armature. Accordingly, the distance between the two positions thus marked on the screen represents an armature travel corresponding to the thickness of the shim. In this manner, the horizontal displacement axis of the cathode ray screen can be calibrated.

The brightness control circuit designated in block 4 is connected to transducer 3, and its output is applied to grid terminal Z of oscilloscope 2. It functions as described above to increase the potential of the grid of the cathode ray oscilloscope and thereby brighten the trace on the screen during armature motion.

To complete the gauging system, a scanning circuit designated in block 5 is utilized to successively scan each of the relay contact pairs 8, 10 and 12 and provide output voltage pulses indicative of the condition of each of these contact pairs, i. e., whether any pair is closed or open. The contact pairs 8, 10 and 12 are activated by the motion of armature 61 via a suitable mechanical coupling designated schematically by the member 62. While only three contact pairs were shown, obviously any number at all could have been included without altering the description of operation of the dynamic gauging circuit. One contact of each pair is grounded, and the other is connected to scanning circuit 5. The scanning circuit is so constructed that when all contact pairs are open it provides a step type output voltage E_y of the type depicted in the graph of Fig. 9, each step on this wave form identifying a particular contact pair. This output voltage is applied to the active terminal Y of the vertical deflection electrodes of the cathode ray oscilloscope in block 2. The result is that in the absence of any horizontal deflection voltage applied to the cathode ray oscilloscope the scanning circuit will cause a series of vertically displaced spots to appear on the screen of the cathode ray oscilloscope. By causing the scanning circuit to cyclically scan all pairs of contacts repetitively at a high rate of speed, and providing the cathode ray oscilloscope with the horizontal deflection voltage produced by the transducer in block 3, these spots are caused to move

horizontally across the screen of the cathode ray oscilloscope. These spots are very close together, due to the much greater rate of repetitive scanning of each contact pair by the scanning circuit in block 5 than the highest speed at which armature 61 can vibrate. This combined with the fact that armature 61 still can be repetitively vibrated at a sufficient rate so normal persistence of the oscilloscope screen retains the image of any spot until the armature has returned to the position corresponding to that spot, gives the visual effect of continuous parallel lines on the screen. The scanning circuit is responsive to closure of any contact pair to cause the step on the output step wave identified with that pair to be slightly vertically displaced, as indicated by the dotted lines in the graph of Fig. 9. Hence, closure of any particular pair of relay contacts causes a slight vertical displacement in the horizontal line associated with that contact pair on the oscilloscope screen. Consequently, very accurate measurement of the armature position at which a particular contact pair closes or opens is obtained. As an example of the magnitudes involved, a scanning rate at which the scanning circuit scans 16 contact pairs in 32 microseconds has proven satisfactory. At this rate, the scanning circuit is responsive to the condition of any contact pair for an interval of 2 microseconds, and successively returns to scan it every 32 microseconds. Assuming that the armature moves between its release and operate position at a velocity of 30 inches per second, which would be quite high for a commercial relay, the position of the armature can only change by approximately 1 mil in the interval between successive scans of any contact pair. Hence, the accuracy of measurement of closure of a contact pair is about 1 mil, which is highly satisfactory for most relays. If higher accuracy is desired, it can be obtained by adjusting the component circuits of the composite scanning circuit to provide a higher rate of scanning. This will be evident from the detailed description of the scanning circuit given below.

In Fig. 10 is shown a representation of the trace which will appear on the screen of the cathode ray oscilloscope when a relay is gauged in accordance with the above-described arrangement. Each of the horizontal lines depicts operation of a particular contact pair. A downward jog in a line indicates closure of a contact pair and an upward jog in the line, proceeding from a left-hand to a right-hand direction, indicates opening of a previously closed contact pair. These directions are based on the assumption that a positive potential applied to active terminal Y of the oscilloscope causes the spot on the oscilloscope screen to be deflected upward, which is customarily the case. The distance of each of these jogs from the extreme left edge of the line with which it is associated gives the displacement of the relay armature from its fully operated position at which that contact pair operated or released, depending on whether the jog is up or down. In the event a particular contact pair chatters when being opened or closed, or at any time during the armature cycle, a series of vertically displaced jagged lines will appear disposed about the horizontal line associated with that contact pair. Accordingly, a complete and simultaneous picture of the operation of all the relay contacts relative to armature position is provided.

SCANNING CIRCUIT

The scanning circuit comprises a free cycling ring of monostable multivibrators, each stage in the ring being capacitively coupled to the following stage, and the last stage capacitively coupled back to the first stage to form the closed ring. The number of stages in the ring is the same as the number of contact pairs to be tested, and each stage is associated with a particular contact pair in the manner now to be described. Referring to Fig. 11 there are shown three stages of the complete multivibrator ring, these being denoted 1st stage, 2nd stage and 3rd stage. A final stage, designated as the *n*th stage, is

depicted in outline form only, since all stages are identical. Although not shown in Fig. 11, it is to be understood that between the 3rd and the n th stages any number of stages may be included, each of these identical with the 1st, 2nd and 3rd stages, and connected to each other in the same manner as the interconnections shown between the 2nd and 3rd stages. The interconnection between the 1st and 2nd stages is basically the same as between the 2nd and 3rd, but includes an auxiliary circuit later to be described. The n th stage is interconnected back to the 1st stage in the same manner as the 1st stage is coupled to the 2nd stage. The input terminal of each stage is designated I, and the output terminal is designated II. The plate 130 of vacuum tube A1 included in the 1st stage is coupled through a condenser 131 to output terminal II. Output terminal II is connected through closed switch K, which serves a purpose to be later described, to the input terminal I of the 2nd stage. In that stage, input terminal I is coupled by a condenser 133 to the control grid 135 of vacuum tube A2 in stage II. Vacuum tube A2 is identical with vacuum tube A1 in the 1st stage. The plate 137 of vacuum tube A2 is coupled through a condenser 139 to the output terminal II of the 2nd stage. Condenser 139 is identical with condenser 131 in the 1st stage. Output terminal II of the 2nd stage is connected to the input terminal I of the 3rd stage. Input terminal I of the 3rd stage is coupled by a condenser 141, identical with condenser 133 in the 2nd stage, to the grid 143 of vacuum tube A3 in stage III. Vacuum tube A3 is identical with vacuum tube A1 in the 1st stage. This manner of interconnection between the 2nd and 3rd stages is identically repeated between the 3rd and 4th stages, the 4th and 5th stages, etc. to the last or n th stage. The n th stage is then coupled back to the 1st stage in the same manner, its output terminal II being connected to the input terminal I of the 1st stage. Thus, a closed ring of " n " stages of monostable multivibrators is formed, corresponding to " n " contact pairs to be tested. Since each stage in the ring functions in an identical manner, the description of all stages will be given by reference to the 1st stage.

This stage includes two vacuum tubes A1 and B1, which may conveniently be enclosed in a single envelope 148. They could equally well be in separate envelopes. The cathodes 149 and 151 of tubes A1 and B1, respectively, are connected together to one terminal of a resistor 153, the other terminal of that resistor being grounded. The plates 130 and 155 of tubes A1 and B1, respectively, are connected together through series connected resistors 159 and 161. The junction point of resistors 159 and 161 is connected to a source of positive direct-current potential B+ which provides operating potential for the plates of tubes A1 and B1. Source B+ is also connected to one terminal of the series connection of resistors 163, 165 and 169, the free terminal of this series connection, which is the terminal of resistor 169, being grounded. The grid 171 of tube B1 is connected through grid current limiting resistor 173 to the junction of resistors 163 and 165. Accordingly, grid 171 is at a positive potential determined by the magnitude of the voltage of source B+ and the potential division factor set by the ratio of the sum of the resistances of resistors 165 and 169 to the sum of the resistances of resistors 165, 169 and 163. Condenser 175 connected between ground and the junction of resistors 163 and 165 provides an alternating-current ground connection for grid 171 of tube B1. The grid 171 of tube B1 is connected to the plate 130 of tube A1 through the coupling condenser 177. The grid 145 of tube A1 is connected through a condenser 147 to input terminal I, and also is connected through grid limiting current resistor 179 to the junction of resistors 165 and 169. Hence, it is at a positive potential determined by the magnitude of the voltage of source B+ and the potential division factor set by the ratio of the resistance of resistor 169 to the sum of the resistances

of resistors 163, 165 and 169. Evidently, this positive potential will be smaller than the positive potential applied to the grid 171 of tube B1 as described above. Accordingly, the grid of tube B1 is at a higher positive direct-current potential than the grid of tube A1.

With this arrangement, when the 1st stage is in its stable state and no positive voltage impulse is applied to the condenser 147 connected to the grid 145 of tube A1, the fact that the grid 171 of tube B1 is at a higher positive potential than the grid of tube A1 results in conduction of tube B1 and cut-off of tube A1. The reason both tubes cannot conduct simultaneously is that all the plate current of tube B1 passes through common cathode resistor 153, thereby establishing a cathode bias beyond the cut-off potential of tube A1. When a positive square-shaped pulse derived from output terminal II of the n th stage is applied to the 1st stage input terminal I connected to condenser 147, since the charge on a condenser cannot instantly change, the leading edge of the pulse will appear at the grid 145 of tube A1 and raise the grid potential above the level of cut-off. Tube A1, therefore, begins to conduct. The sudden nature of this rise in grid potential produces a sharp rise in the plate current of tube A1 and, therefore, a sharp drop in the voltage existing at the plate 130 of tube A1. This negative-going pulse at plate 130 is applied to condenser 177, which was initially charged from source B+ through resistor 159. Since the charge on condenser 177 cannot instantly change, this negative voltage pulse passes through the condenser and appears at the grid 171 of tube B1. The net grid potential of tube B1, therefore, drops below the cut-off level, and tube B1 stops conducting. With tube B1 cut off it no longer raises the potential of common cathode resistor 153, so that tube A1 can continue to conduct even though the positive triggering pulse applied to input terminal I has by then charged condenser 147, so that the pulse is thereafter effectively isolated from the grid 145 of tube A1. The stage is thereby in its unstable state. However, condenser 177 now begins discharging through resistor 159, source B+, ground, by-pass condenser 175 and resistor 173. Since condenser 175 has a very large capacitance, and is in series with the discharge circuit of condenser 177 it has little effect on the time constant of this discharge circuit. The time constant of the discharge circuit is therefore very closely given by the product of the capacitance of condenser 177 and the sum of the resistances of resistors 159 and 173. When condenser 177 has discharged sufficiently so that the potential at the grid 171 of tube B1 rises to the grid cut-off potential of tube B1, tube B1 begins conducting. This raises the potential of common cathode resistor 153 and so causes tube A1 to cut off. The stage thereby returns to its stable state. When tube A1 cuts off, the potential of its plate 130 rises, producing a positive going voltage impulse which is applied through condenser 131 to the output terminal II of the 1st stage. This pulse thereby appears at the input terminal I of the 2nd stage, passing through the contacts of switch K, which is closed while the scanning circuit is in operation. From terminal I the pulse passes through condenser 133 of the 2nd stage thereby triggering the 2nd stage in the same manner as the 1st stage was triggered by the pulse from the n th stage applied to its input terminal I. It should be noted that although the 2nd stage initially received a negative pulse from the plate 130 of tube A1 when tube A1 began conducting, this had no effect on the 2nd stage since at that time tube A2 in that stage was in the cut-off condition and so could not react to a negative pulse applied at its grid.

Thus, each stage in the ring provides a positive trigger pulse for activating the succeeding stage, and the interval between application of triggering impulses to succeeding stages, which is the time from the instant the A tube of any stage begins conducting and the B tube cuts off to the instant that the A tube cuts off and the B tube re-

sumes the conducting condition, is solely dependent on the discharge time constant of any stage and can be selected as desired. This is in contrast with the scanning circuits heretofore known which require an external source of timed triggering pulses to produce successive activation and deactivation of each stage in the ring. This attribute of the scanning circuit described herein, which may be denoted a free cycling scanning circuit, permits a greatly simplified and more economical dynamic relay gauging test set than has heretofore been attainable.

The triggering off of the B tube of any stage, and the interval during which it remains cut off, is utilized to provide the desired stepwave impulses having the wave shape shown in Fig. 9 for controlling the vertical deflection of the cathode ray beam of oscilloscope 2, and also for scanning each contact pair to be tested. This is accomplished by utilization of the modulating vacuum tubes C1, C2, C3, etc., shown in Fig. 11, one of these tubes being associated with each stage in the scanning circuit. This will be explained by reference to the 1st stage, since precisely the same description is applicable to all stages.

The plate 181 of modulating tube C1 is provided with positive potential from positive direct-current source B+ applied through the rheostat 183 connected to plate 181. The cathode 184 of tube C1, as is the cathode of the "C" tube of each stage in the scanning circuit, is connected through a common cathode resistor 185 to a common source of positive direct-current potential E₁, smaller than the potential provided by source B+. The source E₁ provides bias for all the C tubes, which cannot be provided with self-biasing condensers because such condensers would distort the square shape of the voltage signal successively appearing at the grid of each C tube and across the common cathode resistor 185. The grid 182 of tube C1 is connected to the junction of series-connected resistors 187 and 189, the other terminal of resistor 187 being connected to the plate 155 of tube B1, and the other terminal of resistor 189 being connected to the terminal of a potentiometer 191 which is grounded at its other terminal. Associated with resistor 191 is a variable potentiometer arm 193 which can be adjusted to tap all or any part of the voltage existing across resistor 191. One of the contacts of a contact pair 195, representing one of the contact pairs which is to be tested, is connected to the potentiometer arm 193. The other contact of contact pair 195 is grounded.

Series-connected resistors 187, 189 and 191 act as a voltage divider for applying a definite proportion of the voltage existing at the plate 155 of tube B1 to the grid 182 of tube C1. The magnitudes of the voltage bias source E₁ and of common cathode resistor 185 are adjusted so that when tube B1 is cut off the high positive potential existing at its plate is adequate to produce at the grid 182 of tube C1 a potential which causes tube C1 to conduct. The magnitude of the plate current of tube C1, and consequently of the current passing through cathode resistor 185, is adjustable by means of rheostat 183 connected to the plate of tube C1. When tube B1 is conducting, its plate potential is inadequate to provide sufficient positive potential for the grid of tube C1 to cause tube C1 to conduct, so that it remains cut off. Thus tube C1 is normally non-conducting. However, at the instant when tube B1 is cut off as a result of the application of a trigger impulse to input terminal I of the 1st stage, as described above, tube C1 begins conducting and produces a positive potential across cathode resistor 185 of a magnitude dependent on the setting of rheostat 183 connected to the plate 181 of tube C1. This potential will persist so long as tube C1 conducts, which will be determined by the time required for tube B1 to again begin conducting as a consequence of the discharge of the condenser 177 connected between the grid of tube B1 and the plate of tube A1, as described above. Tube C1 will cut off at the instant that tube B1 becomes con-

ducting. That is very nearly the same instant as that at which tube A1 cuts off, and thereby provides a triggering impulse to input terminal I of the 2nd stage. The triggering impulse applied to the 2nd stage results in cut-off of tube B2 in that stage, in the same manner as was described above with reference to the 1st stage. Consequently, tube C2 in the 2nd stage, which is connected in the 2nd stage in the same manner as tube C1 is connected in the 1st stage, will become conductive at very nearly the same instant as tube C1 associated with the 1st stage becomes non-conductive. This process continues stepping from stage to stage around the ring scanning circuit, so that the voltage across common cathode resistor 185 is successively representative of the cathode potential produced by the successive conduction of each of the C tubes.

Referring further to the operation of tube C1, which is identical with the operation of any of the C tubes in the scanning circuit, when the contacts of contact pair 195 close they short-circuit a part of the resistor 191. Since the voltage applied to the grid 182 of tube C1 is a fraction of the plate voltage of tube B1 determined by the ratio of the sum of the resistances of resistors 189 and 191 to the sum of those resistances added to the resistance of resistor 187, short-circuiting all or part of resistor 191 changes the potential of grid 182 and, therefore, changes the plate current of tube C1 and the potential it produces across common cathode resistor 185. In the case where the resistance of resistor 187 is considerably larger than the sum of the resistances of resistors 189 and 191, the result of contact closure will be to decrease the part of the plate voltage of tube B1 which is applied to grid 182. Hence, the plate current of tube C1 will decrease and the voltage across common cathode resistor 185 will decrease. The extent of this voltage decrease is adjustable by potentiometer arm 193.

The common conductor 186 connects the cathodes of all the C tubes to common cathode resistor 185, and the terminal 188 of that resistor is the output terminal of the scanning circuit. By staggering the settings of the rheostats connected to the plates of the C tubes, which, illustratively, is rheostat 183 in the 1st stage, the plate current of tube C1 when it is conducting can be made slightly less than the plate current of tube C2 when it is conducting; the latter current can be made an equal amount less than the plate current of tube C3 when it is conducting; the latter current can be made an equal amount less than the plate current of a corresponding tube C4 in a 4th stage which may be included in the scanning circuit; etc. The result is that the voltage at output terminal 188 will increase positively in discrete steps in response to the successive conduction of tubes C1, C2, C3, etc., up to a maximum when the C tube of the *n*th stage conducts.

It will return to the initial value when tube C1 of the 1st stage conducts in response to the triggering impulse derived from the *n*th stage when that stage returns to its quiescent state, and the entire process will then repeat around the ring. Hence, the desired stepwave potential variation of the output of the scanning circuit will result. In addition, as pointed out above, closure of the contact pair 195 associated with tube C1 of the 1st stage causes a slight decrease in the voltage which tube C1 produces across common cathode resistor 185. The same situation applied to closure of the contact pair associated with each of the other C tubes in the scanning circuit. Accordingly, the potential of any step in the stepwave voltage will be slightly smaller when the contact pair associated with the C tube which produced that step is closed. For application to oscilloscope display, the output terminal 188 of the scanning circuit is connected to active terminal Y of the vertical deflection electrodes V-V of oscilloscope 2, the other terminal of those electrodes being grounded, as shown in Fig. 11. The vertical position of the spot on the oscilloscope screen thereby varies in the same manner as the potential variation shown in Fig. 9;

and when swept horizontally by the operation of the transducer, as described above, produces a screen trace of the kind illustrated in Fig. 10.

Those features of the circuit shown in Fig. 11 which were not heretofore mentioned will now be described. Since the production of steady horizontal lines in the trace on the screen of the cathode ray oscilloscope requires a steady positive potential at the grid of each C tube at the instant of cut-off of the B tube of the stage in the scanning circuit with which that C tube is associated, and an almost instantaneous drop of this potential below the level at which that C tube can conduct when the B tube again begins conducting, it is necessary to provide a coupling between the grid of each C tube and the plate of the associated B tube to compensate for the distributed capacitance of the resistors associated with the grid of the C tube. In the case of tube C1 in the 1st stage, this would be the distributed capacitance of resistors 187, 189 and 191. Such capacitance, having a finite charging time, tends to slope the top of the square voltage impulse derived from the plate of tube B1. A compensating coupling is accomplished by connecting a small variable trimmer condenser 199 between the grid 182 of tube C1 and the plate 155 of tube B1, and adjusting it until the voltage at the grid 182 remains precisely constant from the instant tube B1 cuts off to the instant when it resumes conduction. While this description has been given with reference to the 1st stage, an identical arrangement exists in each of the other stages of the scanning circuit.

The scanning circuit may begin spontaneous cycling as soon as the required positive source potentials B+ are applied as described above. However, since all stages are identical, simultaneous triggering of more than one stage may occur due to the switching transients initiated as a result of applying those potentials. As a result, more than one stage would be in its activated state at any instant. The net potential across common cathode resistor 185 would then derive from the potential corresponding to the conduction of more than one C tube, so that the trace on the screen on the cathode ray oscilloscope would include spurious lines interpolated between the true scanning lines, and perhaps cause obliteration of all the desired scanning lines. To prevent this, output terminal II of the 1st stage is connected to one terminal of a switch K, the other terminal of which is connected to input terminal I of the 2nd stage. With this arrangement, the scanning circuit cannot cycle beyond the 1st stage when switch K is open, and all stages will, therefore, revert to their quiescent state even if a switching transient initially causes multiple stage activation. By applying the source potentials B+ to the scanning circuit when switch K is open, all stages will remain quiescent while any switching transients are dissipated. When switch K is subsequently closed, since this action alone will not impress any transient potentials on any stage of the scanning circuit, all stages will remain in their quiescent state. However, the complete ring is now closed and will continuously cycle as described above once any stage is triggered into its activated state. Such triggering can be provided by applying a sudden positive voltage surge to the input terminal I of any of the stages. As an example of a suitable source of such a surge voltage, Fig. 11 shows a push button switch S suitable for momentarily connecting two terminals, 201 and 203, in response to momentary pressure on the push button 205. Terminal 201 is connected to a source of positive direct-current potential B+. Terminal 203 is connected to one electrode of a condenser 207, the other electrode of which is connected to a grounded resistor 209. The junction of the connection between condenser 207 and resistor 209 is connected through a resistor 211 to the input terminal I of any stage of the scanning circuit. For definiteness of description, it is shown connected to input terminal I of the 2nd stage. When push button 205 is pushed, terminals 201 and 203 are momentarily connected and the

positive potential of source B+ is impressed across the series connection of condenser 207 and resistor 209. Since the charge of condenser 207 cannot instantly change, the instantaneous voltage across resistor 209 will be equal to the potential of source B+. This potential will then sharply drop to zero as condenser 207 charges and absorbs the potential of source B+. The result is the production of a sharp positive voltage pulse across resistor 209, which is applied through resistor 211 to input terminal I of the 2nd stage. This pulse activates the 2nd stage, as described above, and since switch K was previously closed, so that the complete ring of the scanning circuit is closed, free cycling of the scanning circuit will continue. Resistor 211 serves to prevent shunting of triggering impulses from output terminal II of the 1st stage around input terminal I of the 2nd stage via the relatively low resistance of resistor 209. This resistance must be relatively low in order to provide a sufficiently short time constant for the series combination of resistor 209 and condenser 207 to provide the sharp positive pulse required to trigger the 2nd stage.

In operation, the scanning circuit described above provides very accurately timed output scanning pulses. It will be noted that this is accomplished inherently within the scanning circuit itself, no external source of timed pulses being required. It is further to be noted that each stage in the scanning circuit actually is utilized to provide two output pulses, one to actuate the succeeding stage and one to actuate the normally non-conducting output tube associated with a particular contact pair. While a multitude of suitable values of circuit components, positive voltage sources and electron tube types would provide suitable operation of the scanning circuit when chosen in accordance with the description of the scanning circuit and its operation presented above, the following values have been found to provide highly satisfactory operation. These are all identified by reference to the numbered components and electron tubes in stage I, but since all stages are identical they apply to the corresponding components and electron tubes in all stages. In the case of sources B+ and E1 and resistor 185, only one of each is required, as these are common to all stages, as described above.

Resistors

Number:	Resistance in ohms
153	3,900
159	3,000
161	3,000
163	110,000
165	8,000
169	39,000
173	16,000
179	16,000
183	50,000
185	820
187	26,000
189	8,000
191	1,000
209	15,000
211	100,000

Condensers

Number:	Capacitance in micromicrofarads
131	30
147	30
175	10 ⁵
177	100
199	variable from 3 to 9
207	100

Tube types:

- A1 and B1—twin triodes in the type 2C51
C1—one of the triodes in the type 2C51

Voltage sources:

(B+) +165 volts

 E_1 +30 volts

Having fully described the invention and its preferred embodiments and typical applications, the following is the subject-matter which is claimed.

What is claimed is:

1. A system for visually displaying the instantaneous positions in the path of travel of a vibratory relay armature at which each of a plurality of contact pairs controlled by said armature are operated, comprising an oscilloscope having a screen, a pair of lateral deflection controls, a pair of vertical deflection controls and an intensity control, a transducer responsive to the instantaneous displacement of said armature from a fixed reference position to develop a lateral deflecting potential of a magnitude closely linearly proportional to said displacement, brightness controlling means for deriving from said lateral deflecting potential a brightening potential of a magnitude dependent on the rate of displacement of said armature, a free-running high speed scanning circuit operative to generate a cyclically recurring vertical deflecting potential the magnitude of which progressively increases in discrete steps from a fixed minimum to a fixed maximum value, said scanning circuit comprising a plurality of modulating means each of which is associated with a particular one of said contact pairs and with a particular step of said vertical deflecting potential, each of said modulating means operative in response to operation of the contact pair with which it is associated to alter the magnitude of the step of said vertical deflecting potential with which it is associated, said transducer connected to said pair of oscilloscope lateral deflection controls, said brightness controlling means connected to said oscilloscope intensity control, and said scanning circuit connected to said pair of oscilloscope vertical deflection controls, whereby there is produced on said oscilloscope screen a series of vertically separated horizontal lines of substantially uniform brightness, each of which is individual to each contact pair, with the horizontal position of a change in the vertical position of a portion of any line marking the relay armature position at which the contact pair represented by that line was operated.

2. In a system for visually displaying the instantaneous positions in the path of travel of a vibratory relay armature at which each of a plurality of contact pairs controlled by said armature are operated, the combination of an oscilloscope having a screen, a pair of lateral deflection controls, a pair of vertical deflection controls and an intensity control, a transducer responsive to the instantaneous displacement of said armature from a fixed reference position to develop a lateral deflecting potential of a magnitude closely linearly proportional to said displacement, brightness controlling means, said brightness controlling means comprising a differentiating circuit operative to derive from said lateral deflecting potential a brightening potential of a magnitude dependent on the rate of displacement of said armature, a scanning circuit, said scanning circuit comprising a closed ring of a plurality of interconnected stages of multivibrators, each multivibrator stage having a stable state and an unstable state, each multivibrator stage operative in response to the return to the stable state of the preceding multivibrator stage in said ring to go into its unstable state for a period determined solely by its own construction, a modulating electron tube associated with each multivibrator stage, each modulating tube normally being nonconductive, each

modulating tube being rendered conductive by its associated multivibrator stage during the period that stage is in its unstable state, each modulating tube operative while conductive to produce a characteristic step potential, each modulating tube associated with a particular one of said contact pairs whereby operation of that contact pair causes a change in the magnitude of the step potential of that modulating tube while conductive, common output means associated with all said modulating tubes at which the step potentials of all said modulating tubes successively appear, said common output means connected to said pair of oscilloscope vertical deflection controls, said transducer connected to said pair of oscilloscope lateral deflection controls, and said brightness controlling means connected to said oscilloscope intensity control, whereby there is produced on said oscilloscope screen a series of vertically separated horizontal lines of substantially uniform brightness, each of which is individual to each contact pair, with the horizontal position of a change in the vertical position of a portion of any line marking the relay armature position at which the contact pair represented by that line was operated.

3. A system for visually displaying the instantaneous positions in the path of travel of a vibratory relay armature at which each of a plurality of contact pairs controlled by said armature are operated, comprising a cathode ray oscillograph having vertical and horizontal deflecting means and a beam intensity control electrode, a transducer for producing a voltage substantially proportional to the displacement of said armature, means coupling said transducer to one of said deflecting means to cause a beam deflection in accordance with said voltage, a brightness control circuit including a differentiating means and having an input circuit and an output circuit, means coupling said input circuit to said transducer to produce a voltage in said output circuit proportional to the rate of change of said transducer voltage, means coupling said output circuit to said intensity control electrode whereby said beam intensity is made substantially proportional to the velocity of said beam deflection, and a relay contact scanning means having an output circuit coupled to the other of said deflecting means for applying a different voltage to said other deflecting means for each contact pair scanned, each of said different voltages being further changed by the closure of the associated contact pair.

4. The combination of claim 3 wherein said scanning means comprises a separate normally cutoff amplifier for each contact pair to be scanned, an input circuit and an output circuit therefor, means combining said output circuits in parallel to form said scanning means output circuit, means for sequentially activating said amplifiers for producing a different output voltage for each contact pair scanned, and means for connecting each contact pair to the input circuit of its amplifier to modify its output voltage when said contacts are closed.

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