April 22, 1952 D. L. ELAM 2,594,138

ELECTRONIC INDICATOR

Filed Nov. 1, 1946 5 Sheets-Sheet 1

Fig. 1.

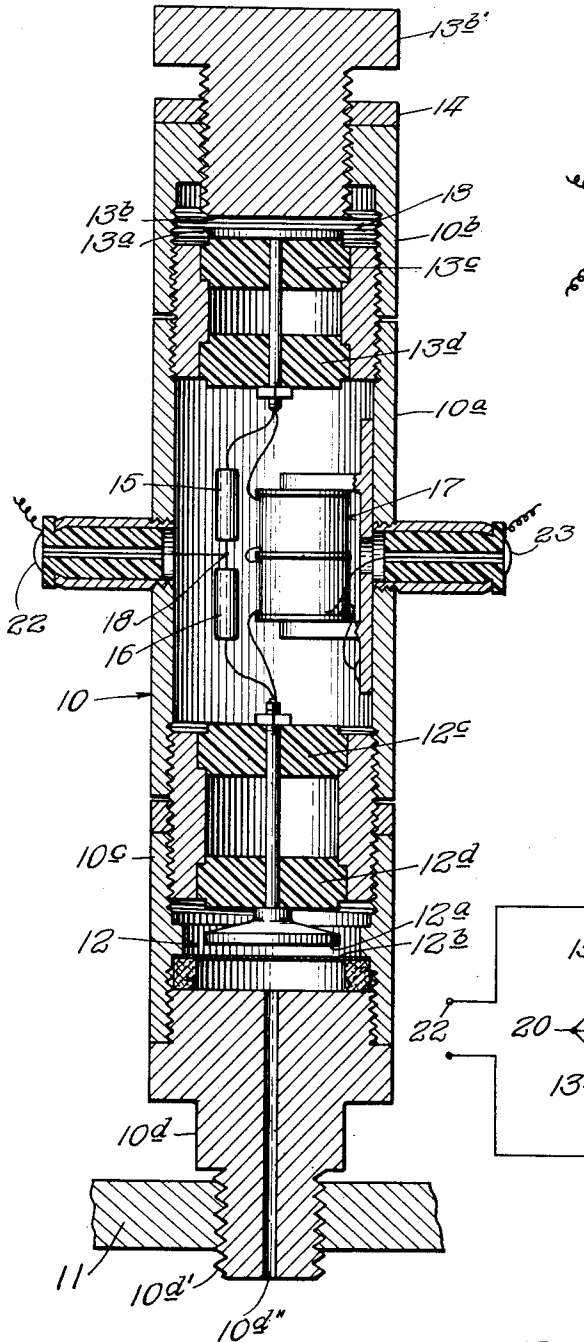


Fig. 2.

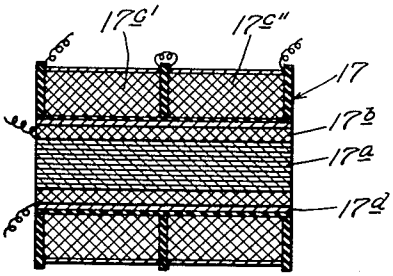


Fig. 3.

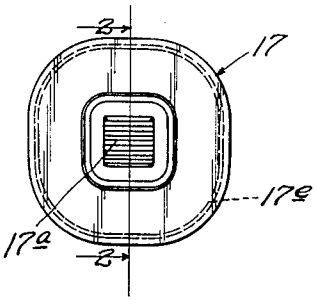
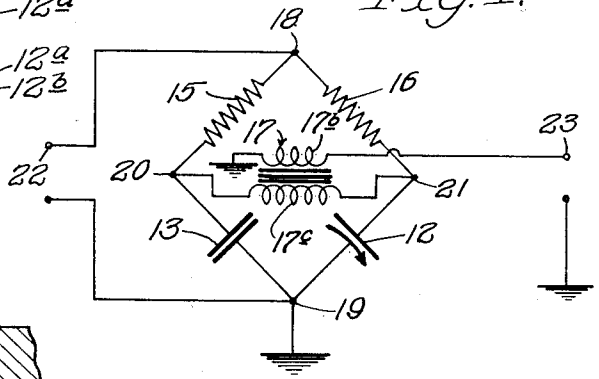


Fig. 4.



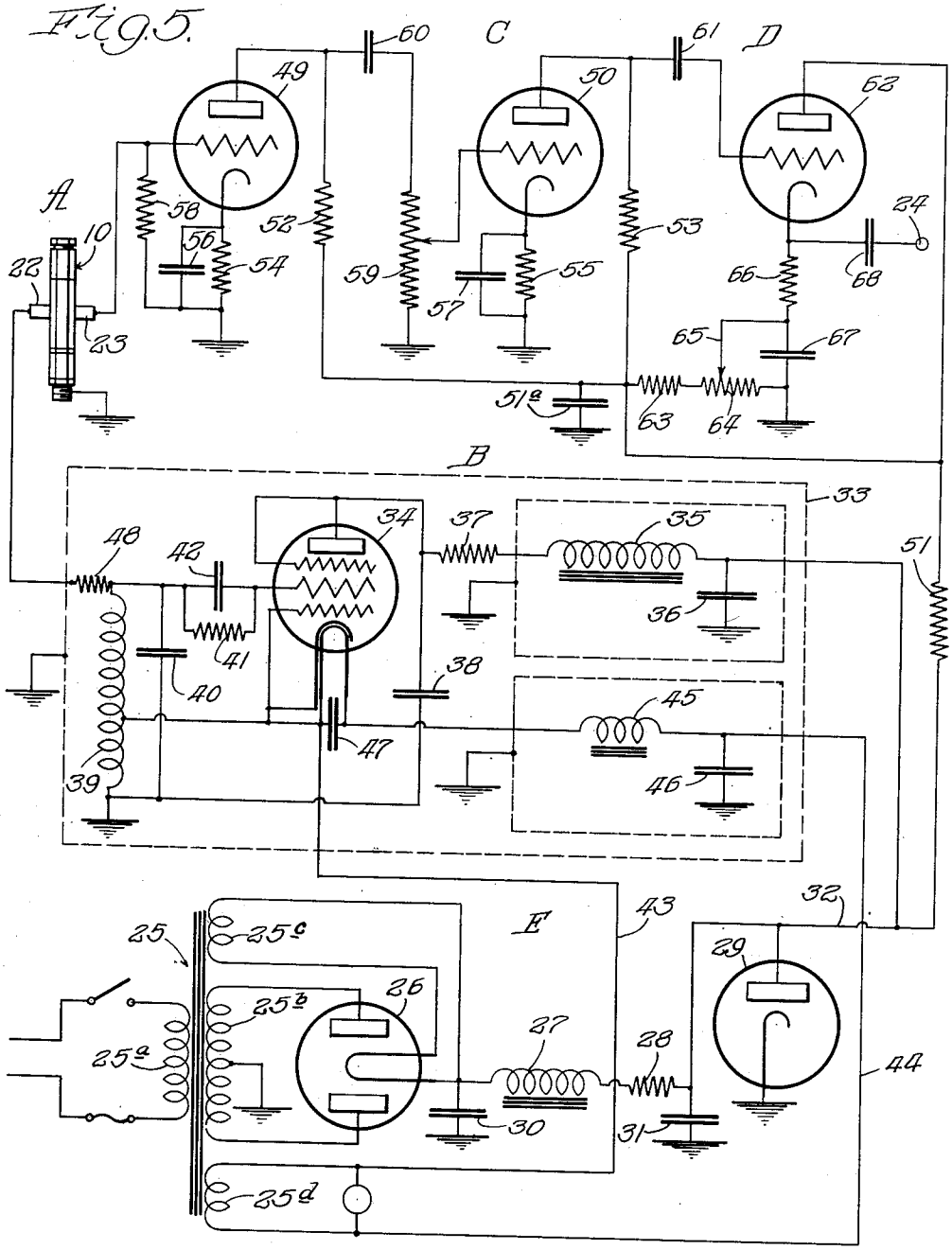
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ELECTRONIC INDICATOR

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Fig. 5.



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ELECTRONIC INDICATOR

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Fig. 6.

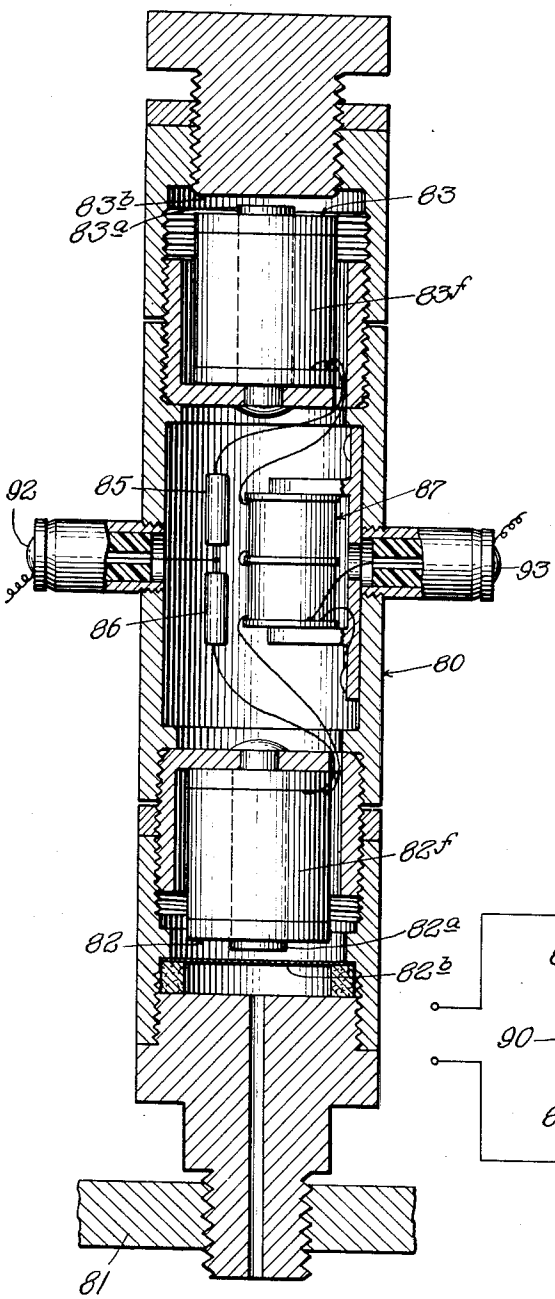


Fig. 7.

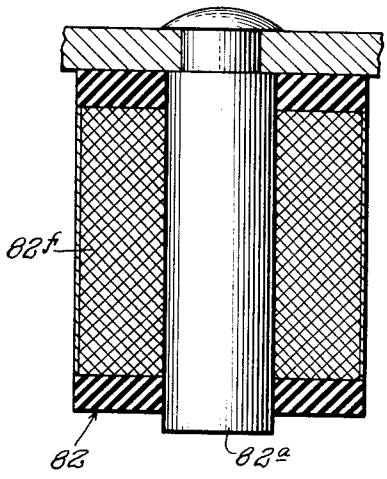
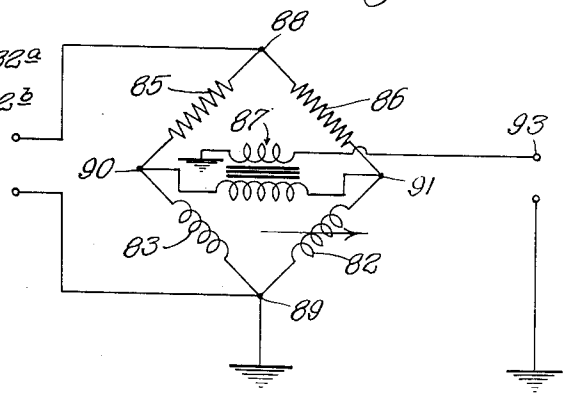


Fig. 8.



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ELECTRONIC INDICATOR

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Fig 9

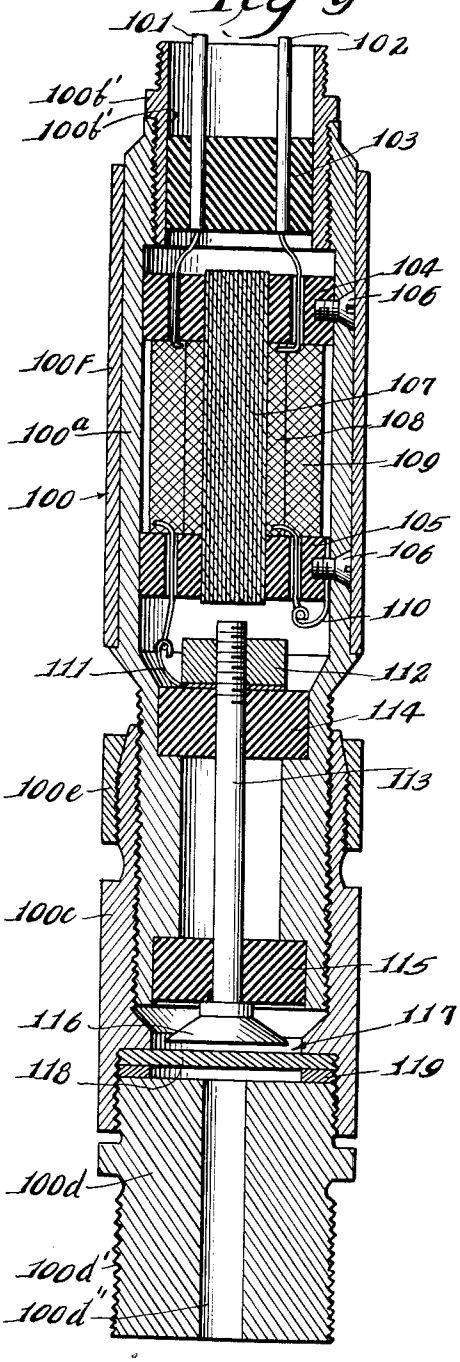
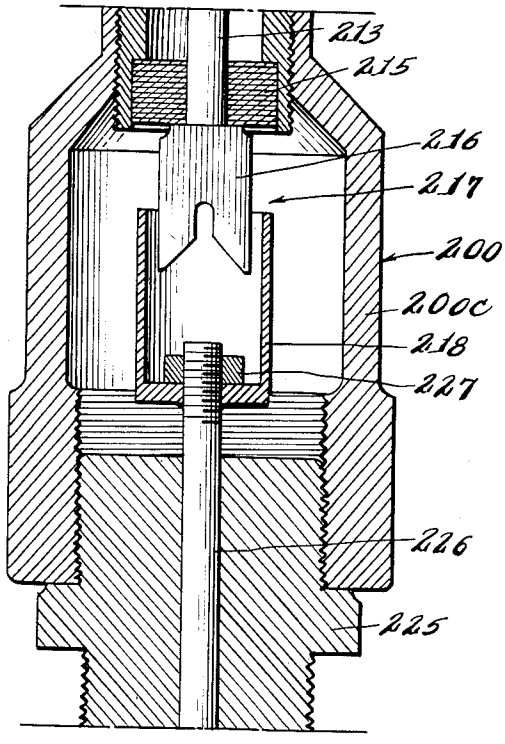


Fig. 10



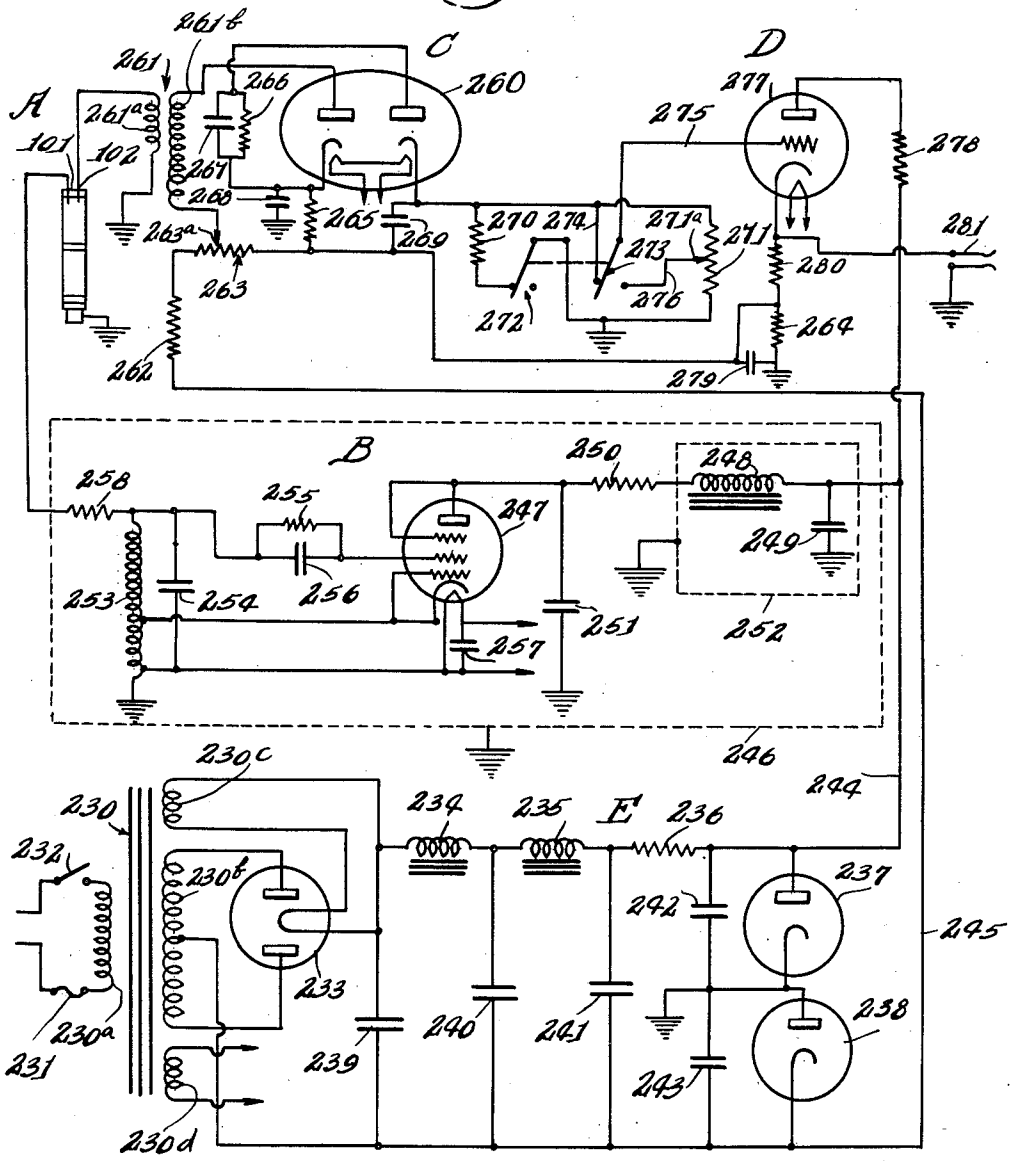
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ELECTRONIC INDICATOR

Filed Nov. 1, 1946 5 Sheets-Sheet 5

Fig. 11.



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2,594,138

UNITED STATES PATENT OFFICE

2,594,138

ELECTRONIC INDICATOR

David L. Elam, Roselle, Ill., assignor to Electro Products Laboratories, Inc., Chicago, Ill., a corporation of Illinois

Application November 1, 1946, Serial No. 707,130

3 Claims. (Cl. 250—27)

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This invention relates to an electronic indicator, and more particularly to a system for translating a mechanical variation into electrical variation and using such electrical variation to provide a desired indication.

This application is a continuation in part of my application for a pressure indicator filed August 11, 1945, as Serial No. 610,325, now abandoned.

Rapidly changing mechanical variations present difficulties and problems of indication not present in connection with slowly changing variations, and it is often desired to obtain an indication of such a rapidly changing mechanical variation. The term "mechanical variation" as used in this specification and claims is intended to include variations pertaining to movement of a device, as for example, movement of a valve stem in a diesel injector, pressure variations in pneumatic or hydraulic mediums, and other physical variations and wave movements with the exception of electrical variations.

For example, it may be desirable to obtain an indication of pressure conditions in the cylinder of an internal combustion engine, the cylinder of a pump, or the like. The difficulties and problems presented in obtaining such indications are readily seen to differ from the problems present in connection with obtaining an indication of slow variations. For instance, where it is desired to provide an indication of the pressure in the storage tank of a compressed air system, a conventional pressure gauge is satisfactory. However, when it is desired to measure the instantaneous pressure conditions at any time in the cylinder of an internal combustion engine which may be operating at several thousand revolutions per minute, a gauge is obviously of no use. Various types of electrical indicating arrangements have heretofore been provided for such pressure conditions, but practically all of them have operated as a function of the rate of pressure change, which is undesirable in that such devices could not measure static conditions when desired.

I have overcome these and other difficulties by providing a system comprising a source of high frequency carrier voltage waves, means for modulating these waves as a function of instantaneous conditions in the object under test, and means for utilizing the modulated portion of such wave to indicate the mechanical variation being tested. My improved indicator operates on a change in reactance, and means are provided for eliminating at least a portion of the carrier wave so that modulation of such wave corresponds to the mechanical variation being measured.

A feature of my invention is that the mechanical variation is changed into an electrical variation in the form of modulation of a high frequency wave, as, for example, a one hundred kilocycle wave of considerable power, as 40 to

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100 volts peak-to-peak swing. Providing the electrical variation in the form of modulation of a high frequency wave (amplitude modulation in the particular case illustrated in the drawings of this application) results in an indication which is truly dependent on the mechanical variation being measured, and not on the rate of change thereof. That is, this apparatus enables static pressure or other mechanical conditions to be indicated on an oscilloscope screen, for example, whereas commercial prior art indicating arrangements are unable to do this. Moreover, by making it possible to use high frequency the envelope variation is made in such closely spaced steps, even when the time axis is considerably expanded on the oscilloscope screen, that an apparently continuous pressure curve is provided.

Another feature which contributes substantially to the desirable operation of this indicating arrangement is the particular discriminator or clipper circuit used. Ordinary rectifying arrangements for removing all or most of the bottom half of a modulated carrier completely remove the carrier, leaving only the variation in amplitude of the envelope thereof (speaking of an amplitude modulated carrier) as the energy wave. Where this is done it is impossible to indicate static pressure conditions on an oscilloscope screen; but by removing most of the negative swings of the carrier without removing any of the positive portions of the modulated portion of the high frequency waves, the carrier continues through to the oscilloscope screen and enables indication of pressure level even when the same remains constant.

One embodiment of my invention incorporates impedance means variable as a function of the mechanical variation under test, a corresponding manually adjustable impedance means, and two other impedance elements in a single pick-up unit in a bridge arrangement. Use of a bridge arrangement and location of all the elements thereof in the unit mounted adjacent the source of mechanical variation, as for example on a wall of a chamber having therein a variable pressure to be indicated, provides means which can be satisfactorily balanced and which will provide a correct electrical indication of mechanical variations in the chamber. In this embodiment the provision of the manually adjustable balancing means is a very important factor, particularly where the pick-up is used in association with a chamber at a relatively high temperature as for example a cylinder of an internal combustion engine. No amount of balancing the bridge circuit on a laboratory bench would mean anything when the temperature of the pick-up was considerably raised in use, probably several hundred degrees above that at the working bench. The convenient manual adjusting means, however, enables the pick-up to be brought up to operating temperature and then properly and accurately balanced with a turn

or two of a wrench, so that the bridge circuit is properly balanced at the operating temperature, and the electrical indication is brought to zero when the pressure in the chamber is at zero, with variation of the pressure varied impedance element then providing known indicating variations.

Another embodiment of my invention utilizes a variable reactance in series with a fixed impedance to translate the mechanical variations into electrical variations, and then utilizes electronic means to eliminate at least a portion of the carrier wave, such electronic means comprising overbiased tubes, the bias on at least one of said tubes being variable in order to determine the amount of the carrier wave which is to be eliminated. In this embodiment of my invention means are provided to overcome the plate to cathode capacitance of the aforementioned tubes in order that the entire unmodulated portion of the carrier wave may be eliminated if desired, together with means for selectively removing the carrier component of the modulated voltage wave while retaining substantially unaltered the outline of the modulated envelope. In this embodiment of my invention means are also provided for changing the impedance of the output circuit to a desired value in order that the wave may be fed to the deflection plates of an oscilloscope.

These and other features and advantages of this invention will be apparent from the following specification and the drawings, in which:

Figure 1 is a longitudinal sectional view through a pick-up embodying my invention; Figure 2 is a longitudinal sectional view of the output transformer, along the line 2—2 of Figure 3; Figure 3 is an end view of the transformer shown in Figure 2; Figure 4 is a schematic circuit diagram of the pick-up arrangement shown in Figure 1; Figure 5 is a schematic circuit diagram of the entire system, including the pick-up and the oscillator, amplifier, discriminator, and power supply associated therewith; Figure 6 is a longitudinal sectional view of another form of pick-up comprising a modified form of my arrangement embodying certain of my invention; Figure 7 is a fragmentary sectional view of one of the reactance elements; Figure 8 is a circuit diagram of the pick-up arrangement shown in Figure 6; Figure 9 is a longitudinal sectional view through a pick-up comprising another embodiment of my invention; Figure 10 is an enlarged fragmentary longitudinal sectional view through the bottom portion of a pick-up comprising another modification of my invention; and Figure 11 is a schematic diagram of a circuit designed to be utilized with the form of my invention shown in Figures 9 and 10.

In order to make the description of the entire system or combination more readily understandable, I will first describe one form of pick-up unit which operates to modulate the high frequency waves as a function of mechanical variations.

While I may employ either an inductive or capacitive form of pick-up, I prefer the capacitive form because it permits high frequencies of the order of 100 kilocycles to be used. The inductive form of pick-up will perform satisfactorily with carrier frequencies in the neighborhood of several thousand cycles, and this is fully satisfactory where a relatively slow speed variation is being measured, particularly where there are no substantially instantaneous pressure changes in the general pressure change curve. However, where it is desired satisfactorily to indicate pressure changes which are recurring at a relatively high rate of speed, as in an engine operating at four or five thousand revolutions per minute, or where there are brief but high peak transient surges in the general pressure curve it is necessary to use a high frequency carrier for satisfactory results. Under such conditions as those last mentioned a carrier frequency of at least 10,000 cycles, and preferably of at least 50 or 100 kilocycles, is necessary. At these frequencies the inductive pick-up or modulating portion of my system is not fully satisfactory, and a capacitive pick-up is preferable.

Accordingly, the capacitive type of pick-up unit has been illustrated first, and this will now be described, reference being had more particularly to Figures 1–4. In the particular embodiment of my invention illustrated in these figures, the pick-up comprises a generally cylindrical outer housing 10 made in several parts for convenience. These are here shown as comprising a central barrel portion 10*a*, an upper portion 10*b*, a lower portion 10*c*, and an end member 10*d*. The end member 10*d* has a reduced threaded portion 10*d'* adapted to be received in a correspondingly threaded opening in a wall 11 of the chamber where the pressure indication is to be made, as a wall of the cylinder of an internal combustion engine or a pump, for example. This end member 10*d* has passageway means therethrough providing communication between the interior of the pressure chamber and the interior of the pick-up housing, this being here shown as the single bore or opening 10*d''*. All metal portions of the housing and of the elements within it, and particularly the reactive elements, are preferably made of the same metal, and preferably of a metal with a relatively low temperature coefficient, as for example steel.

Mounted in the pick-up housing 10 are a pair of impedance elements having capacitive reactance, these being here indicated in general as 12 and 13. The capacitive reactance element 12 is here shown as comprising the fixedly mounted plate 12*a* and the movable cooperating plate 12*b*, air acting as a dielectric therebetween. The plate 12*b* is preferably a thin diaphragm of tough metal, as spring steel or phosphor bronze, and this diaphragm flexes as a function of pressure changes in the chamber effective against the lower side of the diaphragm (speaking with respect to the particular position of the parts as illustrated in Figure 1), this flexing or movement of the diaphragm varying the distance between the condenser plates 12*a* and 12*b* and thus varying the capacity of this impedance element 12. In practical pick-ups which have been constructed in accordance with my inventions, it is desirable to keep the housing diameter down to about 1½ inches or less, and the capacity present in the impedance element 12 (when the diaphragm is unstressed) is of the order of 10–15 microfarads, this capacity being increased to as much as double or more its initial value when the diaphragm is exposed to high pressure. The diaphragm plate 12*b* is fixedly mounted at its edges in the housing portion 10*c*, as illustrated; and the plate member 12*a* is fixedly mounted by insulating mounting members here identified as 12*c* and 12*d*. The edges of the diaphragm plate 12*b* are in direct contact with the housing, as this plate and the housing are grounded in op-

eration, as by the connection between the housing end member and the wall of the pressure chamber.

The other capacitive reactance element 13 is here shown as comprising a fixedly mounted plate 13a held in place and suitably insulated by insulating supporting members 13c and 13d. Cooperating with this fixed plate member 13a is another condenser plate member 13b, this comprising the face of a threaded adjustment member having means enabling convenient rotation thereof at one end, as a hexagonal portion here identified as 13b', this adjustment member being threaded into the upper housing member 10b. A lock nut 14 is associated with this member to enable it to be locked in adjusted position in the particular form shown, although it will be understood that any desired locking arrangement may be used.

The pick-up housing also encloses another pair of corresponding impedance elements here shown as comprising the resistors identified as 15 and 16. In the particular unit being described these may have a resistance value of the order of 100,000 ohms for satisfactory results, although it will be understood that resistors which vary substantially from this value will still provide operative results. Increasing the resistance value gives some increase in sensitivity, but maximum power transfer is effected when the impedance of this pair of elements is substantially the same as the impedance of the capacitive elements at the particular frequency being used, 100,000 cycles in the particular device being described. The pick-up housing also incorporates a transformer here identified in general as 17, this transformer being shown more particularly in Figures 2 and 3.

Referring now to these last mentioned figures, the transformer will be seen to comprise a central core portion 17a, as of laminated or powdered metal of high magnetic permeability, a secondary or output winding 17b, and a split or balanced primary winding comprising the parts 17c' and 17c'', an electrostatic shield comprising a grounded split metal sleeve 17d being interposed between the coils in order to ensure magnetic transfer and to prevent capacitive reflection or reaction on the circuit.

Referring now more particularly to Figure 4, the manner in which the elements within the pick-up housing are connected will be described. The circuit will be seen to comprise a bridge consisting of the corresponding capacitive reactance elements 12 and 13 on the one hand and the corresponding resistance elements 15 and 16 on the other hand. The capacitive element 12 is indicated in the diagram by a symbol showing it to be variable, as the capacity of this element varies during operation as a function of the variation in the pressure conditions effective upon the diaphragm. While the capacitive element 13 is represented by a symbol indicating its capacity to be fixed, it will be understood that this is fixed only in operation; i. e., as has been explained before, the capacity of this element is manually adjustable to balance the bridge after the pick-up unit has been brought up to operating temperature, and it is only thereafter that it remains fixed. The resistors 15 and 16 are, of course, always fixed. The high frequency voltage or carrier waves are supplied, through means to be hereafter more fully described, between a pair of opposite corners of the diamond bridge connection, these being here identified as the corners 18 and 19; and the desired modulated high frequency output is taken off from the other pair of corners of the diamond bridge arrangement, these being here identified as 20 and 21. The actual input to the device, while here indicated as a two-wire input for simplicity of illustration, is actually a one-wire input, as by a shielded cable, to the terminal 22, since the other part of the circuit is completed through ground, the corner 19 of the bridge arrangement being grounded, this connection point 19 comprising the housing of the pick-up unit in practice. The amplitude modulated high frequency output, modulated as a function of variation of the capacity of the condenser element 12, is developed between the points 20 and 21 through the primary 17c of the transformer, this being shown as a single winding for simplicity of illustration, and is transferred to the secondary 17b. The secondary has one end grounded to the casing or housing of the pick-up unit, and the other end connected to the terminal 23, providing the output terminal of the pick-up unit adapted to be connected to the amplifier and discriminator. It will be readily apparent that if a high frequency wave is developed between the terminal 22 and ground by any appropriate means, as an oscillator, that there would be no output developed between the output terminal 23 and ground so long as the bridge is balanced. Accordingly, after the pick-up is brought up to operating temperature, where such is different from normal room temperature, the capacity element 13 is manually adjusted to bring the bridge to balance when pressure in the pressure chamber is at zero. Thereafter increases in pressure in the chamber, during operation of the indicating system, vary the capacity 12 and thus vary the amount of high frequency carrier developed between the output terminal 23 and ground; i. e., provide an output which consists of a carrier wave amplitude modulated as a function of the pressure variations, in the particular case here being described, although it will be apparent that other forms of modulation or bridge variation could be used.

Referring now more particularly to Figure 5, the general system and its operation will be described. The system illustrated comprises a pick-up unit A, as for example of the character just described; an oscillator B for supplying the high frequency input to the pick-up; an amplifier C for amplifying the modulated output of the pick-up; a discriminator D for providing a single curve indication on an oscilloscope screen, without loss of the high frequency waves; and a power supply unit E. The output of the discriminator is supplied from the terminal 24 to the desired indicating means, as the vertical deflection plate system of an oscilloscope, this latter not being shown since any suitable commercial oscilloscope may be used.

Referring first to the power supply unit E, this is here shown as comprising the transformer 25 having a primary 25a adapted to be connected to a suitable source of electrical energy, as the conventional 110 volt, 60 cycle alternating current. The transformer includes a high voltage center grounded secondary 25b having its ends connected to the two plates of a full wave rectifier tube 26, which may be of tube type No. 5Y3GT, for example. A low voltage winding 25c supplies cathode current for the rectifying tube; and another low voltage secondary 25d supplies cathode-filament current for the tubes

of the other electronic portions of the apparatus. The positive rectified output of the rectifier tube 26 is here shown as developed through a filter arrangement comprising the choke 27, which may have a value of ten henries and the resistor 28, which may have a value of 5,000 ohms, to the plate of a voltage regulating tube 29, which may be of tube No. VR150, this tube having its other terminal or cathode grounded. The desired filter effect is obtained by associating with it elements 27 and 28 and a pair of condensers 30 and 31 of suitable value, as for example 10 microfarads. A regulated source of plate or B plus voltage maintained substantially constant at 150 volts is thus provided in the lead or wire 32.

Referring now more particularly to the oscillator, that portion of the circuit diagram surrounded by the dotted line box 33 indicative of grounded shielding, this will be seen to comprise as its principal operative element the pentode tube 34, which may be of tube type No. 6V6. This tube has its positive plate supply delivered to its plate and screen grid through further filtering means here shown as comprising a choke 35, which may be of 50 millihenries inductance, a condenser 36, which may be of .25 microfarad capacity, and a resistor 37, which may be of 4,000 ohms. The plate and screen grid are by-passed to ground through a condenser 38, which may also be of .25 microfarad capacity. The oscillator circuit is of a conventional type using a tapped inductance 39 shunted by a fixed capacity 40, which may be of .0005 microfarad capacity, in conjunction with an inductance of five millihenries, to provide an operative oscillator frequency of about 100 kilocycles. One end of the tank circuit is connected to ground; the other end of the tank circuit is connected to the signal grid of tube 34 through a grid leak and condenser combination which may comprise a resistor 41 of 15,000 ohms and a condenser 42 of .0015 microfarad; and the tap off of the inductance 39 is connected to the cathode and suppressor grid. Heater current is supplied to the heater of the tube 34 through a circuit including the wire 43 on the one hand, and the wire 44 on the other hand, the latter passing through another filter section here shown as comprising a choke 45, which may be of 1.5 millihenries and a condenser 46 which may have a capacity of .25 microfarad; and the heater terminals are shunted by an audio frequency by-pass condenser 47, which may have a capacity of .25 microfarad. This oscillator is capable of providing high frequency voltage waves of considerable power, of the order of 100 volts peak-to-peak swing across the output terminals; and these high frequency waves are delivered through the blocking resistor 48, which may have a value of 10,000 ohms, to the input terminal 22 of the pick-up.

The high frequency or carrier wave thus delivered to the pick-up is modulated by the bridge circuit therein as a function of the pressure or other mechanical variation being indicated, as has been heretofore more fully described, and the modulated carrier (developed between the terminal 23 and ground) is delivered to the amplifying section here indicated in general as C, here being shown as comprising two tubes 49 and 50 in cascade, although it will be understood that any appropriate number of stages may be used. In the particular amplifier here being shown and described the tubes 49 and 50 may be of tube type No. 6SF5GT, provided with plate voltage through a circuit including the 15,000 ohm filter resistor 51 and filter condenser 51*a*, which might have a value of 10 microfarads, and the two .1 megohm resistors 52 and 53. The tubes are here shown as self-biased by the cathode resistors 54 and 55 each shunted by the by-pass condensers 56 and 57. For the particular tubes named the cathode resistors may have a value of 5,000 ohms and the by-pass condensers capacities of .015 microfarad. Grid loading resistors 58 and 59 are used, and the resistor 58 may have a value of .5 megohm and the resistor 59, of the variable type, a maximum resistance of the same value. Coupling between the tubes is here shown as effected through a condenser 60 which may have a capacity of .0001 microfarad.

The amplitude output of the second stage of this amplifier, developed across the plate load resistor 53, is here shown as applied through the coupling condenser 61, which may have a value of .005 microfarad, to the input of the discriminator section comprising as its principal element the tube 62, which may be of tube type No. 6SF5. Biasing voltage for the cathode of this tube is developed by means of a bleeder resistor connected between the positive plate supply and ground and comprising a fixed resistance element section 63, which may be of 75,000 ohms, and a variable resistance section 64, which may be of 5,000 ohms. The slider or potentiometer contact arm 65 is connected to the lower end of a cathode resistor 66, which may have a value of 10,000 ohms; and the biasing portion of the resistor 64 operative at any particular time is by-passed to ground by a condenser 67, which may have a capacity of .5 microfarad.

This discriminator or clipper circuit arrangement is of considerable importance and advantage in an indicator system of the kind here being disclosed. The output of the system is taken off from the terminal 24 connected to the upper end of the resistor 66 through a coupling condenser 68, which may have a capacity of .05 microfarad, and resistor 66 is un-by-passed, i. e., it is not by-passed to ground with a condenser in the conventional manner. By by-passing the operative portion of the bias-determining resistor 64 by the condenser 67, the lower end of the resistor 66 is always kept at ground potential from an A. C. standpoint; but the upper end of this resistor is at a voltage above ground determined by space current flow in the tube 62, not only with respect to the amplitude variations corresponding to the pressure, but also with respect to the high frequency voltage variations of the positive portions of the carrier wave. Adjustment of the amount of bias on the cathode of the tube 62, by variation of the position of the contact 65 on the resistor 64, determines the amount of the negative swings of the carrier voltage which are chopped off or removed, and preferably this is so adjusted that practically all of the negative portions of the carrier voltage swings are eliminated from the output delivered to the terminal 24 and thus to the oscilloscope. However, the positive swings of the high frequency wave go through and provide a resultant indication on the screen of the oscilloscope tube which comprises effectively a completely "shaded in" area between the zero pressure or horizontal axis and a top curve representing the instantaneous pressure. This top curve is very smooth because of the high frequency of the carrier wave which may be used with this system, even when the time axis is stretched out considerably by adjustment of the oscilloscope controls. Moreover, because of

the relatively very high frequency of the carrier wave impulses, very brief transient pressure variations over a time interval as short as of the order of a thousandth of a second are clearly shown up on the oscilloscope screen. Moreover, as has been mentioned before, where this indicating system is being used for devices which can be stopped at a certain pressure condition, as a pump or the like, the pressure is indicated at a particular level, or with a very small diminution as it leaks off through the valves and around the piston packing, by virtue of the fact that the carrier waves or positive voltage swings of the high frequency waves provide an indication at the appropriate level above the zero axis on the oscilloscope tube screen without any change in pressure, since the bridge circuit used will deliver to the output waves of an amplitude determined by the capacity of the capacity element **12**, regardless of whether this capacity is varying or not.

Another form of pick-up is shown in Figures 6 and 7, with its circuit diagram being shown in Figure 8, this pick-up again making use of the bridge principle with all four impedance elements in the pick-up housing, but the two variable impedance elements in this case being inductance elements. This form or modification of my pick-up will now be described with particular reference to these last-mentioned figures, and in order to shorten the description reference numerals **70** higher than those used in Figures 1 and 4 will be associated with parts corresponding in their function.

In this latter form of my invention there is again a general cylindrical housing here identified as **80**, adapted to be threaded into an appropriate opening in the wall **81** of a chamber wherein the pressure variations are to be indicated. Here the reactance elements identified in general as **82** and **83** are inductive rather than capacitive in character. The element **82** comprises a core piece **82***a* cooperating with a flexible diaphragm **82***b*. In this case the core piece **82***a* is encircled by an inductive winding **82***f*, the inductance of this winding being varied by variation of the gap between the center of the diaphragm **82***b* and the adjacent face of the core piece **82***a*, the magnetic circuit being completed through permeable material in the mounting in the upper end of the core piece and in the diaphragm **82***b*, this latter being necessarily of magnetically permeable material in this form of the invention. The corresponding reactance element **83** has its core piece **83***a* within a winding **83***f*, the inductance of this winding being varied by movement of the face **83***b* of the adjustment member toward and away from the adjacent core piece face. This again enables the bridge circuit (incorporating inductive reactance elements in this case instead of capacitive reactance elements) to be readily and conveniently balanced by manual adjustment with the pick-up under operating conditions.

The pick-up also includes other parts and elements necessary to render it operative, including the resistors **85** and **86** and the transformer **87**. As may be best seen in Figure 8, these are connected in a diamond shaped bridge arrangement with the carrier frequency developed between the corners **88** and **89** of the bridge and the output developed across the corners **90** and **91** of the bridge delivered through the primary of the transformer **87**, the secondary of this transformer being connected to ground and to the output terminal **93** of the pick-up. This form of pick-up is fully satisfactory at carrier wave frequencies

at the order of 2,000 or 3,000 cycles per second, and thus provides satisfactory indications under conditions where the "time axis" on the oscilloscope screen is not to be unduly stretched out, and where no exceptionally brief time duration transient pressure variations are encountered.

A modified form of a pick-up unit is shown in Figure 9, this modification doing away with the balanced transformer and the bridge circuit of the first described embodiment of my invention and utilizing electronic means to eliminate the undesired portion of the carrier wave. The pick-up unit is housed in the generally cylindrical housing **100** which for convenience is made up of several parts. An upper central portion **100***a* has an interiorly threaded upper end into which is fitted a complementary threaded upper end portion **100***b*, and said upper central portion has an exteriorly threaded lower end over which is fitted the complementary threaded lower central portion **100***c*. An end portion **100***d* is threaded into the lower end of the portion **100***c*, said end portion having an exteriorly threaded portion **100***d'* adapted to be received in a correspondingly threaded opening in communication with the mechanical variation to be measured, as a wall of the cylinder of an internal combustion engine or a pump, for example. This end member **100***d* has passageway means therethrough providing for communication between the interior of the chamber having the pressure variation or the other mechanical variation to be measured and the interior of the pick-up housing, this being here shown as the single bore or opening **100***d''*. A compression lock nut **100***e* is threaded onto the upper portion of the lower central member in order that plates of the reactance element to be hereafter described may be spaced as desired. An outer cover **100***f* surrounds the upper central portion as shown.

The upper portion of the end member **100***b* is recessed as shown at **100***b'*, and an input lead **101** and an output lead **102** are mounted within said recess, said leads being held in position by the insulating member **103**.

The upper central member **100***a* carries a transformer between the insulating mountings **104** and **105**, said mountings being securely fastened in place by means of the screws **106**. The transformer comprises a core **107** of permeable material, a secondary winding **108** and a primary winding **109**. The secondary winding may comprise about 500 turns of fine insulated wire wound next to the core, and the primary may be made of approximately 2,000 turns of such wire wound directly over the secondary. The core may comprise about eight pieces of black iron wire each of .034 inch in diameter or a powdered iron core.

The input lead **101** extends through the upper transformer mounting and is secured by soldering or other suitable means to one end of the primary winding, while the output lead **102** extends through the transformer mounting and is secured to one end of the secondary winding. The other end of the secondary winding is grounded by means of the soldering lug **110** which is held in contact with the housing **100** by means of the screw **106**, while the other end of the primary winding is secured by soldering or other suitable means to the soldering lug **111**, and said soldering lug is connected by means of the nut **112** to the condenser plate stud **113**.

Said condenser plate stud is carried by the

upper center portion 100a of the housing, being centered therein by means of the insulating mounting plugs 114 and 115, and at the bottom of said condenser plate stud is the flanged portion 116, comprising one plate of a reactance means here shown as a condenser 117. The other plate of said condenser is the diaphragm 118 which is carried by the end portion 100d of the housing and is spaced therefrom by the spacer gasket 119. The diaphragm 118 is preferably a thin diaphragm of tough metal as spring steel or Phosphor bronze in order that it may flex as a function of pressure changes in the chamber effective against the lower side of the diaphragm, thereby varying the distance between the condenser plates 116 and 118 and thus varying the capacitive reactance of this condenser. The diaphragm 118 is fixedly mounted at the edges as shown in Figure 9, and the condenser plate stud 113 which carries the plate member 116 is fixedly mounted by means of the insulating plugs 114 and 115. The edges of the diaphragm 118 are in direct contact with the housing, as this plate of the condenser and the housing are grounded in operation through the connection between the housing and the wall of the pressure chamber.

The plates of the condenser 117 may be separated any desired amount by adjusting the member 100a (which carries the plate 116) with respect to the member 100c (which carries the plate 118), and the said plates may be locked at any desired separation by means of the compression lock nut 100e.

In operation of this embodiment of pick-up device a high frequency carrier voltage wave is fed into the pick-up unit through the input terminal 101. Since the primary 109 of the transformer and the condenser just described are in series, a voltage drop will appear across the circuit including theses elements, and such voltage will be distributed between the primary of the transformer and the condenser depending upon the inductive reactance of the transformer primary and the capacitive reactance of the condenser at the particular frequency employed. It is desirable that the series circuit comprising the inductive member and the capacitive member is not resonant at the frequency employed, and in one embodiment of my invention which I have constructed I have obtained satisfactory results by using a transformer primary winding with an inductance of 25 millihenries. In order to resonate at 100 kc. (which is the frequency used for the carrier wave) the condenser 117 would have to be of 100 micro-microfarads capacitance, while in actual practice this condenser has a capacitance varying from 5 to 10 micro-microfarads.

As the condenser plate 118 flexes as a function of the mechanical variations to be indicated (in this case varying pressure in a chamber) the capacitance and hence the capacitive reactance of the condenser varies, thus changing the distribution of the total voltage of the carrier wave across the respective inductive and capacitive members of the circuit. Obviously these changes occasioned by the varying capacitive reactance could be utilized if taken off either across the condenser or across the inductive member, and I show such electrical variations as being taken off from the secondary of the transformer which is connected between the output terminal 102 and ground. Thus the carrier wave is modulated according to the mechanical variations acting upon the diaphragm 118, and such modulated carrier wave is taken off by means of the secondary winding 108 which is inductively coupled to the primary winding 109, and between the output terminal 102 and ground there exists an alternating carrier voltage which is modulated in accordance with the mechanical variations to which the diaphragm 118 is subjected.

Since the electronic apparatus which may be used with my pick-up unit is always separate from the pick-up unit and may be located a considerable distance from the pick-up, a transmission line is used to carry the impulses from the output terminal of the pick-up unit to the input of the electronic apparatus. I have found it preferable to utilize a step-down transformer in the pick-up unit, thus making it possible to use a low impedance transmission line, as, for example, a 150 ohm line. By this means it is possible to use the pick-up at a considerable distance from the electronic apparatus with only negligible loss, and at the same time pick up only a minimum of undesired noise or other signals. Means may be provided at the input to the electronic apparatus to step the voltage from the transmission line up to a desired level, as, for example, the step-up transformer shown at 261 in Figure 11.

In Figure 10 a modified form of my pick-up unit is shown, only the bottom portion of such unit being shown in the drawing since the upper portion is the same as the apparatus shown in Figure 9. In Figure 10 for convenience of description corresponding parts of the apparatus will be designated by numerals 100 higher than those in Figure 9. The apparatus of Figure 10 is particularly designed to pick-up variations of movement, as for example the movement of a valve stem in a diesel injector, rather than to pick-up variations in pressure as was the apparatus heretofore disclosed.

In the drawing the housing 200 again consists of various parts, the lower central portion only being shown as 200c. Such portion is illustrated as having an interiorly threaded base portion adapted to support the pick-up on the apparatus under test, as the injector head 225. The reactance member 217 comprises the fixed element 216 which forms one plate of the condenser and is fixedly mounted on the condenser plate stud 213 which is supported in the insulating block 215 as in the last described modification of my invention. The other plate of the condenser is the cup-shaped electrode 218 which is mounted on the injector valve stem 226 and is secured against movement relative to said valve stem by means of nut 227. As the valve stem 226 moves up and down the capacitance between the plates 216 and 218 will change, and consequently the capacitive reactance of the condenser 217 formed by said plates will also change.

The condenser is connected in series with the primary of a transformer, as in the modification of my invention disclosed in Figure 9, and such series circuit is adapted to be energized by means of a carrier voltage wave in the same manner as heretofore described, while the varying potential occasioned by the varying capacitive reactance of the condenser is taken off from said pick-up unit by means of the inductively coupled secondary of the transformer in the manner heretofore described.

Referring now more particularly to Figure 11 the general system of operation of apparatus similar to Figure 9 or Figure 10 will be described.

The system is illustrated as comprising a pick-up unit A, as for example a unit of the character shown in Figure 9 or Figure 10; an oscillator B for supplying the high frequency to the input pick-up; electronic means for removing substantially all of the high frequency carrier wave indicated at C; an impedance changing device D for changing the impedance of the electrical variation to a desired value so that it may be applied to an oscilloscope; and a power supply unit E. Obviously if desired the output waves from the pick-up unit A may be amplified by means of a proper circuit, as the circuit shown at C of Figure 5.

Referring first to the power supply unit E, a transformer **230** has a primary **230***a* adapted to be connected to a suitable source of electrical energy, as a conventional 110 volt 60 cycle alternating current line. A fuse **231** and a switch **232** are shown in said line for obvious purposes of control. The transformer **230** includes a high voltage secondary **230***b* having its ends connected to the two plates of a full wave rectifier tube **233**, which may be of tube type No. 5Y3GT, for example. A low voltage winding **230***c* supplies cathode current for the rectifying tube; and another low voltage secondary **230***d* supplies filament current for the tubes for the other electronic portions of the apparatus, such filament connections not being shown in the drawing since they are conventional.

The positive rectified output of the rectifier tube **233** is here shown as being developed through a filter arrangement comprising the choke coils **234** and **235**, which may each have a value of 10 henries and the resistor **236** which may have a value of 1250 ohms, to the plate of a voltage regulating tube **237**, which may be of tube type No. VR150, this tube having its other terminal or cathode grounded. The center of the secondary **230***b* of the transformer is connected to the cathode of another voltage regulating tube **238**, which may be of tube type No. VR75, and the plate of such tube is grounded. The desired filter effect is obtained by means of the choke coils and resistor in connection with the condensers **239**, **240** and **241** which are connected between the two leads just described, and which may each have a value of ten microfarads, and by means of the condensers **242** and **243** which are connected respectively between each of the aforementioned leads and ground. This apparatus provides a regulated source of plate or B plus voltage in the lead **244**, such voltage being maintained substantially constant at 150 volts above ground, and a source of bias voltage in the lead **245**, this voltage being maintained substantially constant at 75 volts below ground.

Referring now more particularly to the oscillator, which comprises that part of the circuit diagram surrounded by the dotted line box **246** indicative of grounded shielding, the pentode tube **247**, which may be of tube type No. 6V6 comprises the principal component. This tube has its positive plate supply voltage delivered to its plate and screen grids through further filtering means here shown as comprising a choke **248**, which may be of 50 millihenries inductance, a condenser **249** which may be of .25 microfarad capacity, and a resistor **250** which may be of 4,000 ohms resistance. The plate and screen grid are by-passed to ground through a condenser **251**, which may also be of .25 microfarad capacity. The filter circuit comprising the choke **248** and the condenser **249** are also shielded as indicated by the dotted line **252**.

The oscillator circuit is of a conventional type using a tapped inductance **253** shunted by a fixed capacity **254** which may be of .0005 microfarad capacity, in conjunction with an inductance of 5 millihenries, to provide an oscillator frequency of about 100 kilocycles. One end of the tank circuit is connected to the signal grid of tube **247** through a grid leak and condenser network which may comprise a resistor **255** of 15,000 ohms and a condenser **256** of .0015 microfarad. The tap off of the inductance **253** is connected to the cathode and suppressor grid. Heater current for the filament of the tube is supplied from the secondary **230***d*, a condenser **257** which may be of .25 microfarad capacity being shunted across said filament. This oscillator is capable of providing high frequency carrier voltage waves of considerable power of the order of 100 volts peak-to-peak swing across the output terminal; and this high frequency carrier wave is delivered through the blocking resistor **258** which may have a value of 10,000 ohms to the input terminal **101** of the pick-up.

The high frequency or carrier wave delivered to the pick-up is modulated therein as a function of the mechanical variation under test, as has been heretofore more fully described, and the function of that portion of the circuit just described is similar to the function of the corresponding portion of the circuit in Figure 5 to wit to deliver a high frequency carrier wave of substantially constant amplitude to the pick-up unit. However the type of pick-up unit illustrated in Figures 9 and 10 does not include means for eliminating the unmodulated portion of the carrier waves as do the pick-up units illustrated in the Figures 1 and 6, and the balance of the circuit to be hereafter described provides means for electronically eliminating substantially all of the unmodulated portion of the carrier wave and for changing the impedance of the modulated envelope to a desired impedance so that the wave may be applied to an oscilloscope. Means are also provided for removing that portion of the carrier within the modulation envelope if desired, and switching means are provided for selectively connecting either the modulated envelope without the carrier or the modulated envelope including the carrier to the impedance changing device. In this connection I have designed apparatus to provide that the modulated envelope will have the same amplitude when the switch is in either position.

While the means for eliminating the unmodulated portion of the carrier wave might comprise one or more triodes or other tubes biased below cutoff, I illustrate such means as comprising the double diode rectifying tube **260** which may be of tube type No. 6H6. It will be understood that two separate diodes may be used in place of the double diode if desired. The modulated output from the pick-up unit is inductively coupled to the rectifying circuit by means of the transformer **261** having a primary **261***a* and a secondary **261***b*. The primary is connected between the output terminal **102** of the pick-up unit and ground, and the carrier wave which varies as a function of the mechanical variation being measured is inductively coupled into the secondary **261***b* and fed to the first plate (reading from the left) in the rectifying tube.

As is commonly known in the art, if the first cathode of the rectifying tube **260** were at ground

potential and the first plate of said tube were at the instantaneous potential of the modulated carrier, the tube would conduct whenever such carrier swings positive, and the output of the tube would include the positive half of the unmodulated carrier as well as the positive modulated portion thereof. In order to avoid this and to eliminate the unmodulated portion of the carrier I overbias the first plate of this rectifying tube, and provide a bias voltage therefor which is substantially equal to one-half the peak-to-peak amplitude of the unmodulated portion of the carrier wave which is delivered to the input of said tube.

This bias voltage is delivered to the tube through the lead 245 which runs between the cathode of the voltage regulating tube 238 and ground and incorporates therein the resistor 262 which may be of the value of 2,000 ohms, the potentiometer 263 which may have a value of 5,000 ohms and the resistor 264 which may have a value of 500 ohms. Since the voltage at the tube 238 is 75 volts below ground, there is normally a D. C. voltage which varies from minus 55 volts to minus 5 volts along the potentiometer 263. The slider 263*a* of such potentiometer is connected to the bottom end of the secondary 261*b*, and consequently without reference to the voltage of the carrier wave there is maintained on the first plate of the rectifying tube 260 a bias voltage of anywhere from minus 5 to minus 55 volts, depending upon the position of the slider 263*a*. In operation of my apparatus the slider is adjusted until the bias voltage is equal to one-half of the peak-to-peak amplitude of the unmodulated portion of the carrier wave, and in consequence thereof the rectifying tube 260 only conducts during the modulated portion of said wave.

I have found that this portion of the circuit fails to remove the entire unmodulated portion of the carrier wave because of the interelectrode capacitance between the first plate and the first cathode of the rectifying tube, and I overcome the effect of this interelectrode capacitance by using two diodes in cascade rectification. In the drawing both diodes are shown as being part of the same tube, although it will be understood that if desired, separate single diodes may be used instead of a tube type No. 6H6 or other dual diode tube.

The rectified carrier with a part of the unmodulated portion eliminated therefrom is taken off from the top of the cathode resistor 265 which may have a value of 50,000 ohms, and is fed to the second plate of the tube through the automatically biasing grid leak network comprising a parallel combination of the resistor 266 which may have a value of 50,000 ohms and the condenser 267 which may have a value of .0005 microfarad. The lead including such network is bypassed to ground by the small condenser 268 which may have a value of .0001 microfarad.

The grid leak network automatically provides a bias on the second plate of the rectifying tube so that such tube only conducts when the voltage exceeds the remaining portion of the unmodulated carrier voltage, and consequently only the positively modulated portion of such carrier is passed through said tube, thereby providing an effective electronic means for eliminating substantially all of the unmodulated portion of the carrier.

In the output circuit of the tube 260 I provide a resistance-capacity network together with switching means movable between two positions, this arrangement being designed to deliver to the following impedance changing stage either the modulated envelope including the carrier wave, or to remove said carrier wave from the modulated envelope and deliver the integrated envelope alone.

The resistance capacity network comprises the condenser 269 which may have a value of .0001 microfarad and the parallel cathode resistance including the resistor 270 which may have a value of 5,000 ohms and the potentiometer 271 which may have a value of 1 megohm. The ganged switches 272 and 273 are operable to selectively deliver to the impedance changing stage D either the modulation envelope and carrier wave complete or merely the integrated modulation envelope. It will be noted that one end of each of the resistors 270 and 271 is connected to the second cathode of tube 260, and that the other end of the resistor 270 is connected to one terminal of the switch 272, while the other terminal of the potentiometer 271 is connected to ground. With the switch in the position as shown in the drawing the small resistor 270 is connected in parallel with the large potentiometer 271 between the second cathode and ground, and said resistor 270 effectively shorts out the potentiometer 271 and lowers the impedance between said second cathode and ground, thereby practically nullifying the by-passing effect of the condenser 269 since said condenser has a very high capacitive reactance at the carrier frequency used, namely 100 kilocycles. With the switch in this position only a very small portion, if any, of the carrier wave contained within the modulation envelope will be by-passed to ground, and the modulation envelope and carrier substantially complete therein will be delivered to the impedance changing stage D through the lead 274 connecting the top of the resistors to the switch 273, through said switch, and through the lead 275.

However should the ganged switches 272 and 273 be thrown to the position other than that shown in the drawing the resistor 270 would be disconnected from ground and thereby removed from the circuit, and the capacitive reactance of the condenser 269 will now be in parallel with the one megohm potentiometer 271. In this event the high carrier frequency will be by-passed through the condenser 269 to ground, while the lower frequency modulation variations will develop a voltage across said potentiometer, and this integrated voltage, being the modulation envelope with the carrier removed therefrom, will be delivered to the impedance changing stage through the lead 276 which connects the slider 271*a* to the switch 273, through said switch, and through the lead 275. The slider 271*a* enables the circuit to be adjusted so that a modulation envelope of the same amplitude will be delivered to the frequency changing stage when the switches 272 and 273 are in either position.

The impedance changing stage D comprises the tube 277 which may be of tube type No. 6J5. Plate voltage for said tube is delivered from the positive high voltage source through the lead 244 and the plate dropping resistor 278 which may have a value of 20,000 ohms. Bias for said tube is developed across the resistor 264 which is bypassed by the condenser 279 which may have a value of .5 microfarad, and the output is taken from the cathode of said tube across the resistor 280, which may have a value of 2,000 ohms, said output being delivered to the jack 281. One

terminal of said jack is grounded as shown, and the jack is adapted to be connected to a conventional oscilloscope.

This last described circuit comprises a cathode follower which changes the impedance of the modulation envelope to a desired figure, as 2,000 ohms in the case illustrated. Furthermore the circuit acts as a discriminator in the same manner as the circuit illustrated in Figure 5, for the cathode resistor 280 is un-by-passed while the bias determining resistor 264 is bypassed, thereby always maintaining the bottom end of the resistor 280 at A. C. ground potential and the upper end of said resistor at a voltage above ground determined by space current flow in the tube 277, not only with respect to the amplitude variations corresponding to the mechanical variations, but also with respect to the high frequency carrier wave variations. By this means when the switches 272 and 273 are in the position shown in drawing the modulation envelope together with its high frequency component may be delivered to the jack 281.

While I have shown and described certain embodiments of my invention, it is to be understood that it is capable of many modifications. Changes, therefore, in the construction and arrangement may be made without departing from the spirit and scope of the invention, as disclosed in the appended claims.

I claim:

1. Pick-up means of the character described for translating a mechanical variation into an electrical variation, including: a circuit comprising a first impedance means and a second impedance means in series, said second impedance means being variable as a function of said mechanical variation; means coupled to said circuit for energizing said circuit with an alternating carrier voltage wave; means connected to said circuit for eliminating at least a portion of said carrier wave, such means comprising at least one rectifying tube; means connected to said eliminating means for ultizing the varying potential across one of said impedance means occasioned by the variation of said second impedance means, said last mentioned means comprising means selectively operable for removing the carrier component of the varying potential while retaining said varying potential substantially unaltered; switching means movable between two positions, said switching means in one position providing the varying potential together with its carrier component, and in the other position providing the varying potential with the carrier removed; and compensating means connected to said switching means for providing that said varying potentials have the same amplitude when said switching means are in either position.

2. Pick-up means of the character described for translating a mechanical variation into an electrical variation, including: means to generate an alternating carrier voltage wave of substantially constant amplitude; means to modulate said carrier wave in accordance with a function of said mechanical variation, said last named means comprising a single series circuit consisting of a single inductance member and a variable condenser in series, said condenser comprising a member adjustable with respect to a movable member whereby the capacitance therebetween can be set as desired, said movable member being adjacent said member and movable as a function of said mechanical variation whereby a variable capacitance exists between said members; means connecting said carrier wave generating means across said single series circuit only, a secondary inductance member inductively coupled to said single inductance member whereby the varying potential across said single inductance member occasioned by the varying capactive reactance of said condenser is induced in said secondary inductance member, means connected across the output of said secondary inductance member to eliminate those portions of the modulated carrier wave having an amplitude value less than a predetermined amplitude value, and means to adjust said predetermined amplitude value.

3. Pick-up means of the character described for translating a mechanical variation into an electrical variation, including: means to generate an alternating carrier voltage wave of substantially constant amplitude; means to modulate said carrier wave in accordance with a function of said mechanical variation, said last named means comprising a single series circuit consisting of a single inductance member and a variable condenser in series, said condenser comprising a member adjustable with respect to a movable member whereby the capacitance therebetween can be set as desired, said movable member being adjacent said member and movable as a function of said mechanical variation whereby a variable capacitance exists between said members, means connecting said carrier wave generating means across said single series circuit only; a secondary inductance member inductively coupled to said single inductance member whereby the varying potential across said single inductance member occasioned by the varying capacitive reactance of said condenser is induced in said secondary inductance member, rectifier means connected across the output of said secondary inductance member to eliminate those portions of the modulated carrier waves having an amplitude value less than a predetermined amplitude value, and biasing means connected to said rectifier means.

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