

1,156,412.

P. M. LINCOLN.
ELECTRIC WATTMETER.
APPLICATION FILED NOV. 5, 1913.

Patented Oct. 12, 1915.
5 SHEETS—SHEET 1.

FIG. I.

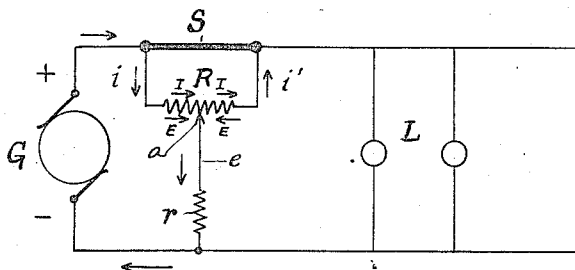


FIG. II.

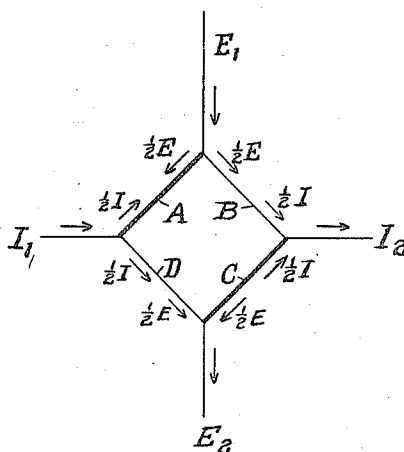
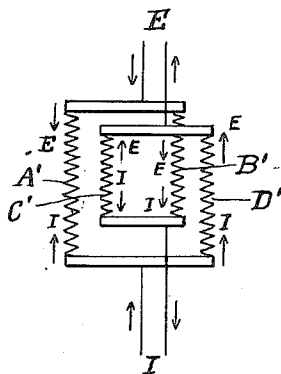


FIG. III.



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FIG. IV.

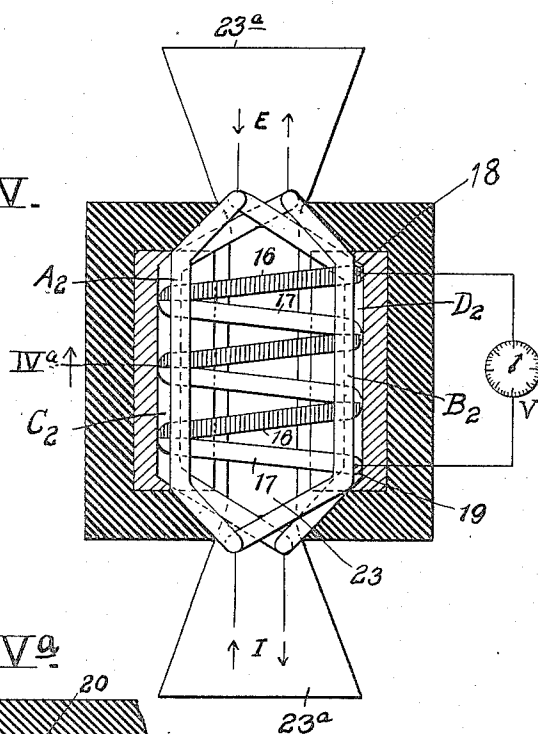


FIG. IV^a.

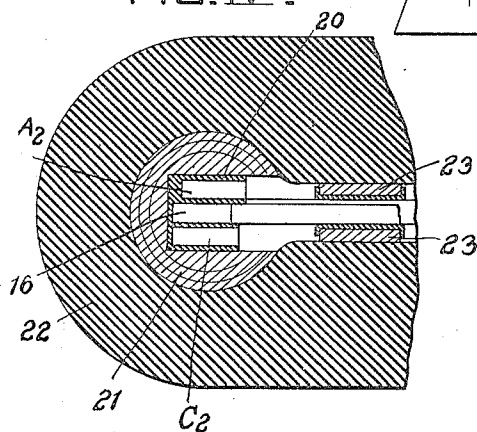
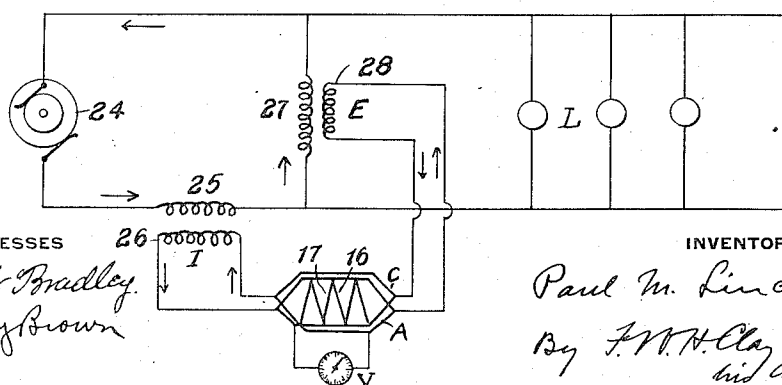


FIG. V.



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5 SHEETS—SHEET 3.

FIG. VI.

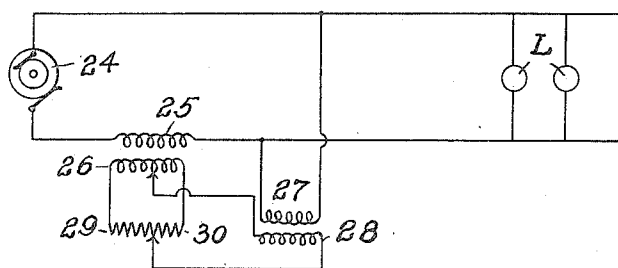


FIG. VII.

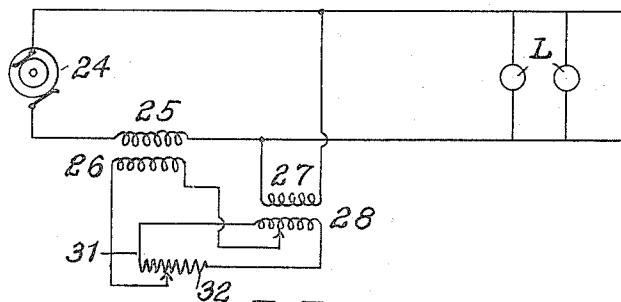


FIG. VIII.

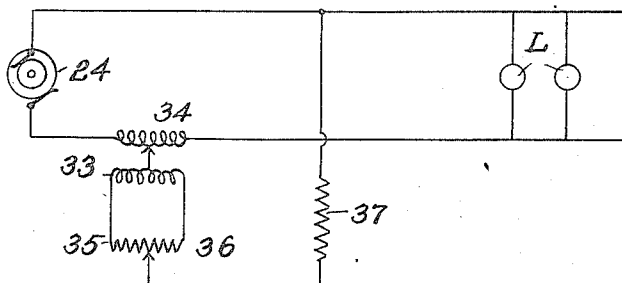
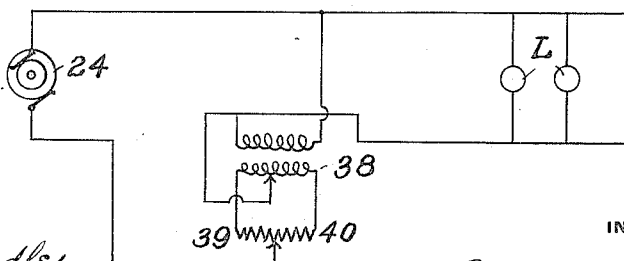


FIG. IX.



WITNESSES

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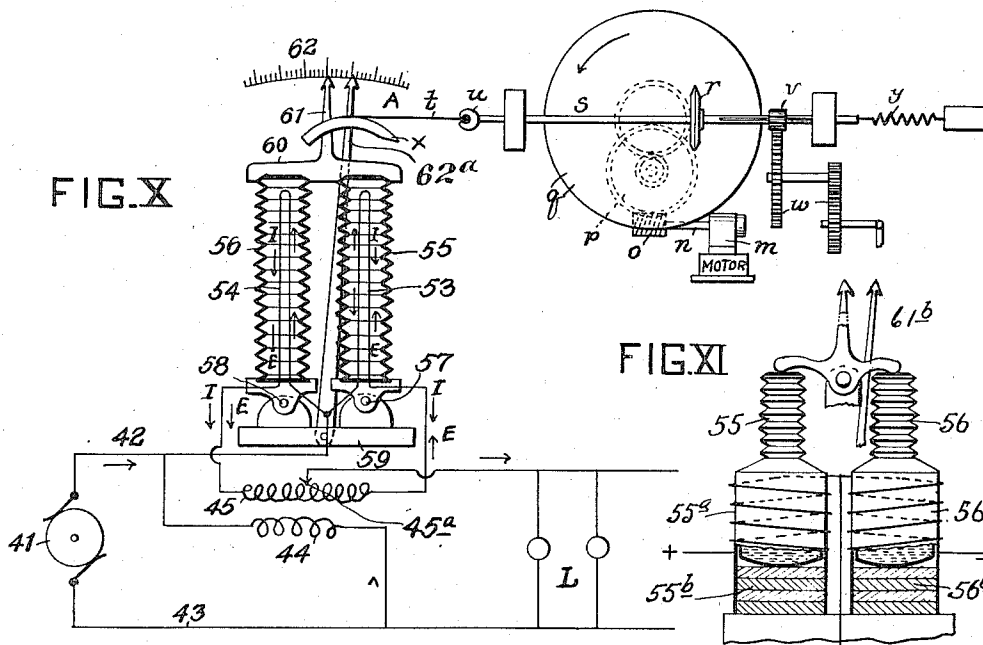
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5 SHEETS—SHEET 4.



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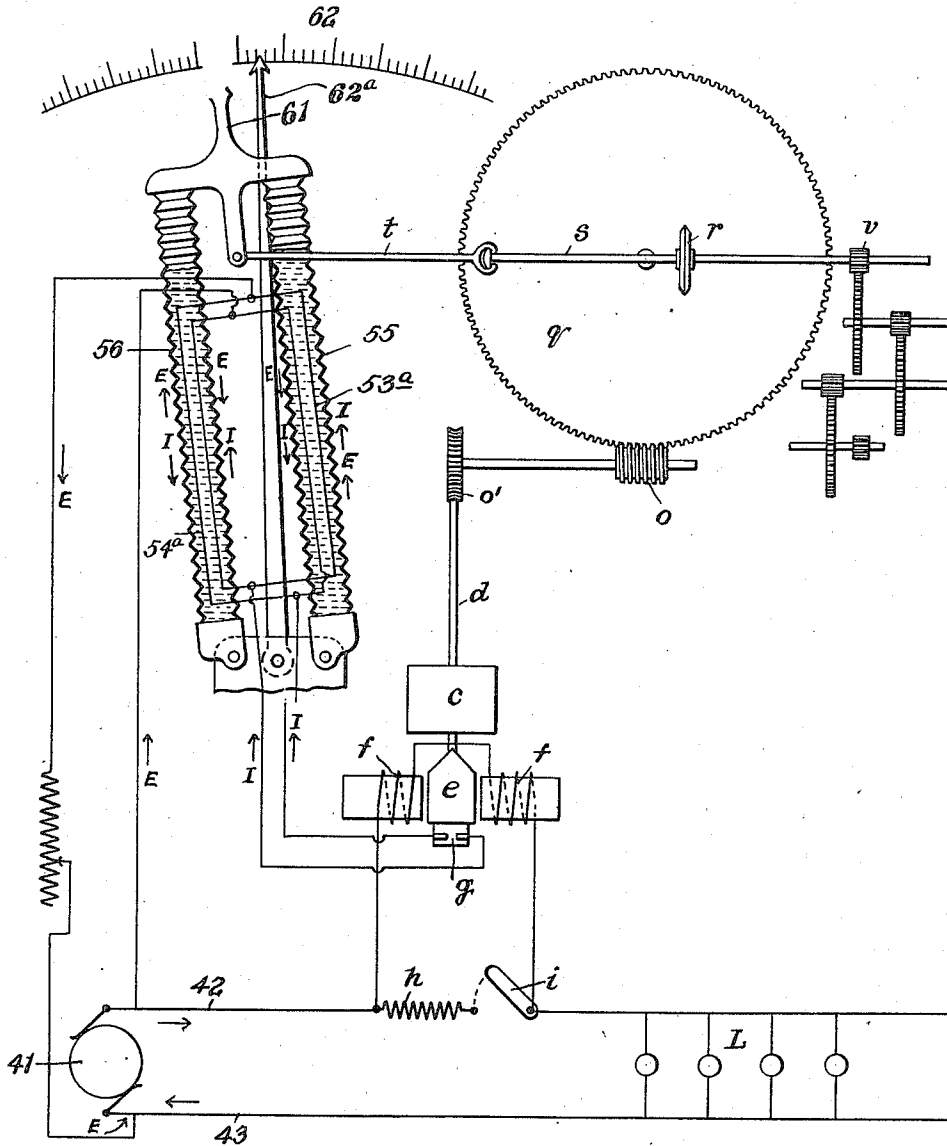
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5 SHEETS—SHEET 5.

FIG. XII.



WITNESSES

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ELECTRIC WATTMETER.

1,156,412.

Specification of Letters Patent.

Patented Oct. 12, 1915.

Application filed November 5, 1913. Serial No. 799,320.

To all whom it may concern:

Be it known that I, PAUL M. LINCOLN, a citizen of the United States, residing at Pittsburgh, in the State of Pennsylvania, have invented certain new and useful Improvements in Electric Wattmeters, of which the following is a specification.

My invention relates generally to means for measuring electric power. It is more particularly concerned with such instruments as measure the differential effects of two circuits derived from the circuit to be measured and energized respectively in proportion to the voltage and in proportion to the current of the circuit to be measured.

The primary object is to produce a more direct, simple, accurate and reliable device for measuring electric power.

Other objects are to produce an instrument that will accurately indicate energy and at the same time permit of an adjustable and sufficiently large lapse of time between the occurrence of an energy flow and its indication; to produce a superior maximum demand and integrating wattmeter, and to generally improve such instruments as will hereinafter appear.

I have illustrated the invention in several preferred forms in the accompanying drawing, wherein—

Figures I and II are diagrams of simple circuits to illustrate the principle of my invention. Fig. III is a diagram illustrating one method of using the differential effects of two currents. Figs. IV and IV^a show respectively in horizontal section, and a partial vertical section along the line (IV^a) of Fig. IV, one form of construction for thermo battery. Fig. V is a diagram illustrating the use of a thermo battery to measure the wattage of an alternating current circuit. Figs. VI, VII, VIII, and IX, are diagrams illustrating several forms of connection for taking off the required currents from an alternating current circuit. Fig. X represents still another form of structure for indicating the effects of the two superposed currents, and also a device for integrating the total amount of energy used in the circuit. Fig. XI shows a modified form of arranging the heating elements or expandible tubes in Fig. X, as will hereinafter be described. Fig. XII, is a diagram and partial vertical section of another form of mechanical construction for indicating the electric power.

Generally stated I measure electric energy by measuring the difference in the thermal or electrical effects obtained by superposing on each other two derived currents which are proportional respectively to the voltage and to the amperage of the circuit to be measured. For example, in Fig. I, supposing the generator G to be supplying the line containing the load L; if we take two taps i i' , at the end of a series shunt S, the current flowing through these taps will depend upon the resistance R of the shunt circuit, and will always be proportional to the current into the load L. Likewise, if we connect the resistance R to the opposite side of the circuit by a shunt lead e containing resistance r , the current flowing through it due to the voltage E, will be proportional to the voltage current on the load L; and if the connection is at the middle point of resistance R in this figure, the heat losses in the two parts i i' , and therefore the temperature rise of the two parts i i' from this source alone will be equal. Likewise, the current in resistance R due to the voltage across series shunt S alone will produce equal heating of the two halves of the resistance R. Therefore with either current I, alone, or the current due to voltage, (E,) alone, the heating as well as other effects due to the current will be the same in the two parts of the resistance R; but when these are superposed the circuit will have the sum of the effects of current I and voltage current E, whereas the lead i' will have the difference between the effects of current I and current E. It is evident that an instrument designed to operate by the differential effects of the currents E and I during any period of time will give an indication proportional to the product of the current and voltage on the load, and therefore indicate the energy or watts in the main circuit.

As a further illustration of the principle, consider Fig. II: Assuming that in the net work of wires indicated we have four equal resistances A, B, C, D; evidently a current flowing from E_1 to E_2 will divide equally through the four resistances as indicated. Likewise the current flowing from I_1 to I_2 , will divide equally, one half traversing each of the four leads as indicated by the small arrows. The heating or any other electrical effects in the conductors A and C will therefore plainly be proportional to the differ-

ence between the values of the current I and the current E; whereas the effects in the conductors B and D will be proportional to the sum of the currents I and E. In some instances, I apply this principle by using the conductors A, B, C, D, as the heating elements of a thermo-electric battery, in which the difference in temperature between the pair of conductors A and C on the one hand, and pair B and D on the other hand, will be the product E times I, and therefore proportional to the true electric energy flowing in the circuits from which the currents E and I are taken, as above described. This may be shown to be true for either direct or alternating current and in the latter case takes cognizance of the phase angle between them, thereby giving true energy in any case. In other instances, I use electric energy directly, as by operating dynamometers by the respective currents in the limbs A, C, on the one hand, and B, D, on the other hand. Or again I make use of the heat produced by the combined derived currents to operate other indicators directly.

In Fig. III, I have arranged resistance elements A', B', C', D', corresponding to the elements A, B, C, D, in Fig. II. If we pass the current due to the voltage of a circuit to be measured, through the net work as indicated by the arrows, it is plain that the elements A' and C' will be heated proportionally to the difference between the currents E and I, and elements B' and D' will be heated proportionally to the sum of the currents E and I. Therefore the difference between the temperature of the pair of elements A', C', on the one hand, and the temperature of the pair of elements B', D', on the other hand, will measure the total energy or watts of the circuit. I therefore measure this difference of temperature in any convenient manner, as for example, by measuring the voltage developed by a thermo-electric battery with opposite joints heated respectively by these pairs of resistance elements. A convenient mechanical embodiment of such a device is shown in Figs. IV and IV^a. Here the bars A₂, B₂, C₂, D₂, are the conductors A, B, C, D, of Figs. II and III, carrying the two currents E and I as before. The pair of resistance bars, A₂, C₂, on the one hand and the pair B₂, D₂, on the other hand, are arranged to inclose respectively the hot and cold ends of a thermo-battery composed of the series of bars 16, 17, the terminals of which thermo-battery 18 and 19 are connected with a voltmeter V. These bars 16 and 17 are preferably made of different cross-sections, in inverse proportion to their thermal conductivity, so that the aggregate heat conduction of all the bars 16 is equal to that of all the bars 17. Since thermal and electric conduc-

tivity are always in constant ratio, the electric conductivity is thus made equal. The heating bars, as shown in Fig. IV^a, especially are covered with insulation 20 and also surrounded by a heat reservoir 21, preferably consisting of heavy metal concentric rings; while the entire system of bars is covered by a heat-and-electric insulator 22. Contiguous to the bars 16, 17, I place heat conductors 23, with radiating wings 23^a. By this means I prevent the escape of any heat otherwise than by traversing the bars 16, 17, and 23, 23, and subsequent radiation by the cooling wings 23^a attached to the bars 23, 23. By use of the adjustable heat reservoir 21, I provide for an adjustable time lag between the flow of energy and its indication by the meter; so that the indicating instrument V may indicate at any time, not the present value of the energy flowing at that instant, but the accumulated effects of the energy which has theretofore been flowing during a previous predetermined time interval. That is the indication is always an indication of the integrated energy over a predetermined period of time, and is what I call a "logarithmic average" indication, because the indication of the energy approaches its true value along a logarithmic curve and according to a law by means of which the actual energy may be shown when the time lag is determined. I shall hereafter describe another indicator for maximum demand.

It will be understood that in dealing with alternating current, the phase relation between current and voltage is important; but it should be noted that a net work such as indicated in Fig. I or such as physically embodied in the device of Fig. IV, will still operate to indicate the true energy, no matter what the phase relation between the current and voltage. For, although when out of phase with each other, the quantity I is not directly additive to or subtractive from, the quantity E in the diagram, yet the difference in heat losses in the cool and hot limbs of the thermo-battery is proportional to that function of E and I which is the expression for the true energy of an alternating current; so that still a measure of the difference of temperature of the two sides of the heated net work is a true measure of energy and is independent of phase relation. Thus in the diagram of Fig. V, if we have an alternating current source 24 in circuit with the load L, we may, by the primary 25 of a series transformer, whose secondary is 26, take off the current I proportional to the amperage; and by another primary 27, of a shunt transformer whose secondary is 28, we may take off a current E proportional to the voltage. These respective currents may be employed for example, to operate a thermo battery 16, 17, by means of resistance as before de-

scribed for Fig. IV, and will give an indication of the true energy.

In various ways the apparatus for dealing with alternating currents may be simplified and varied to suit conditions. For example, in Fig. VI, we may use a two part net work 29—30 instead of a four part net work by taking a middle tap on the secondary 26 of the series transformer for the current element and connecting it in series with the secondary 28 of the shunt transformer for the voltage element, the other end of secondary 28 being connected to the middle point of the two part resistance 29, 30. Again as shown in Fig. VII, the terminals of the current transformer secondary 26 may be connected at one end to the middle point of a two-part resistance 31, 32, and the other end connected to the middle point of the secondary 28 of the voltage transformer.

As shown in Fig. VIII, the voltage transformer may be entirely dispensed with by connecting the middle point of the secondary 33 to the primary 34, while its terminals connect to resistance 35, 36, the middle point of which is in turn connected to the opposite potential through a resistance 37. Again, the current transformer may be dispensed with as shown in Fig. IX, by connecting the line leads respectively to the middle point of the secondary 38 of the voltage transformer and the middle point of the two part resistance 39, 40, in turn connected to the terminals of the secondary 38.

It will be understood that for a given total loss in heating elements, the difference of temperature between the pair of elements A, C, and the pair B, D, will be a maximum, and therefore give the maximum accuracy in the wattmeter when the losses in the heating elements due to the voltage current alone is approximately equal to the losses due to the current element alone; that is, E should be equal to I for full load conditions. Also, accuracy will be increased by making the apparatus independent of temperature conditions of the surrounding atmosphere. For this reason, I prefer to make the voltmeter V of a material having the same temperature co-efficient as the heating members A₂, B₂, C₂, D₂, in Fig. IV. Thus as the resistance of the voltmeter increases demanding a higher voltage to cause a given indication, the heat loss in the heating element also increases, giving a proportionally higher temperature difference between the two ends of the thermo battery.

Instead of using the heat developed by the currents proportional respectively to the current and to the voltage of the line to be measured to operate a thermo battery, I may use it to produce direct mechanical motion, as illustrated in Figs. X, XI, XII.

In Fig. X, the generator 41, leads 42, and

43, transformer 44, 45, load L and line connections, are as just above described, except that the lead 42 carries the current first through a pair of heating wires 53, 54, made in the form of loops, then back to the ends of the secondary 45 and at the middle point 45^a thereof connect to the load L. The looped conductors 53, 54, are placed respectively in corrugated tubes 55, 56, supported by pivots 57, 58, on a fixed block 59 and carrying at their upper end a head 60 provided with a pointer 61 traveling over a scale 62. These tubes 55, 56, are preferably formed with deeply corrugated sides, closed entirely and filled with some liquid easily expansible by heat, such as kerosene. The tubes are free to expand longitudinally when the fluid expands by reason of the heat of the loops 53, 54. Obviously when the two tubes expand the same amount there is no indication of the pointer 61; but if one tube expands more than the other the pointer 61 will travel sidewise, the tubes moving on their pivots 57, 58. From the previous discussion it will be obvious that the current I alone flowing from the lead 42, through the loops 53 and 54, in parallel and back to the ends of the secondary 45, will cause the same expansion in each of the tubes 55 and 56, by equally heating the fluid therein. The current E induced from the shunted primary 44 into the secondary 45, will traverse the path indicated by the arrows marked E, and obviously when superposed on current I will act differentially, causing a heat due to the sum of E and I in one leg and due to the difference in the other. The result will be the greater expansion of the tube 56 than the tube 55 and the pointer 61 will move to the right, thus indicating the wattage of the main circuit. I may obviously use the metal of the tubes 55, 56, itself as the heated conductors 53, 54. Such an indicating device as above described may also be conveniently supplied with an integrating device. As an illustration, I have shown in this Fig. X an integrating mechanism controlled in its movements by the pointer 61. The constant speed motor or clockwork m, by shaft n, worm o, and gears p, drives a friction table q which engages a friction wheel r fixed to a shaft s, which shaft is free to move longitudinally so that its speed depends upon the position of the friction wheel s with respect to the center of the table q. This position of the friction wheel is determined by the wattmeter pointer 61 which is attached to shaft s by a cord t with a universal bearing u. It will be understood that the shaft s, by a pinion v splined thereon, drives any suitable gearing w, carrying any desired indicators after the usual manner of integrating wattmeters. It will be clear that the departure of friction wheel s from the center of the table q is

always proportional to the scale indication of the pointer 61. This can be provided for, if necessary, by the shape of the base x supporting the flexible link or cord t , as will be understood. The link t is kept taut by retractile spring y at the end of shaft s . As the pointer 61 is moved from zero position, it may of course push along an idle pointer 62^a, in the usual manner, to indicate the maximum or extreme position of the pointer 61, thereby showing the maximum logarithmic average demand.

As shown in Fig. XI expansible tubes 55, 56, may be made as part of large reservoirs 55^a, 56^a, in the form of tubes having an adjustable series of blocks 55^b, 56^b, arranged to absorb heat by conduction from the walls and bottom of the reservoirs, so as to vary the amount of heat storage. In this case also I preferably arrange the heating wires corresponding to the loop conductors 53, 54, of Fig. X, by winding them about the reservoirs 55^a, 56^a. By this means I use a volume of fluid which is large in comparison with the volume of the expansible tubes and thus not only exaggerate the indication but provide for any desired amount of time lag in the action as by varying the amount of liquid or the number of the blocks 55^b and 56^b.

As above stated the currents respectively proportional to amperage and voltage ought to be equal in volume at full deflection, in order to get maximum accuracy; and while this condition is easily arranged by means of the transformers, when dealing with alternating currents, it imposes a difficulty when working with direct current, because there would be an undue waste of energy. Thus the resistance in element r of Fig. 1, will waste energy when the useful voltage drop between the point a and the lead i' has the same value in operating with the shunt element alone as the voltage drop between the same points has when working with a series element alone, a condition which is desirable for accurate indication when the circuit is at full load. In Fig. XII I have shown a means of overcoming this difficulty of wasting energy. The indicating apparatus is the same as in Fig. X except that in place of the clockwork m for driving the table q therein, I use a constant speed electric motor c , and connect its shaft d with a small armature e running in the fields f, f , excited directly by series winding having the main current from the line circuit 42, 43, to be measured. By proper winding of fields f, f , and armature e we may obtain any voltage desired at the commutator g , but it will always be proportional to the current of the circuit whose power is to be measured. As before, the current E and this current I traverse one limb of the net-
work in expansion tubes 55, 56, in the same

direction, and the other limb in opposition, as will be obvious from the arrows in the figure.

The fields f, f , may be in some cases, especially when dealing with large currents, excited by a smaller current by using a series shunt as h , connecting it in by closing the switch i . It will be obvious also, that instead of changing the ratio of amperage element by the use of fields f, f , we may change the ratio of the voltage element, by exciting these fields with windings taken across the voltage of the machine, thus getting from the commutator g a current of larger volume and lower voltage. In such case this current would properly be combined with a current from the series shunt h , for measurement. In either case it will be seen that we properly adjust the ratio of currents employed in measuring, to the full line current, without incurring serious resistance losses.

In all the devices described, I employ the same principle of indicating the energy of the electric circuit by the differential effects obtained by superposing a current proportional to the amperage of the circuit, and a current proportional to the voltage of the circuit, combining said two effects to operate an indicator. It will be understood that my invention is not limited to one pair of heating elements or other devices for making the indications, and that the invention is applicable to polyphase circuits by using a plurality of pairs of heating elements, as by merely duplicating the actuating devices of Fig. XI, for example, also duplicating the transformers. I provide for uniformity and certainty of action, especially in the heat operating devices, and eliminate many errors and uncertainties of similar instruments heretofore used; with other advantages which will be obvious to those familiar with the art.

It is evident that I may use as an indicator any device that is responsive to the passage of current, so long as it has the two requisites, (a) that it takes no cognizance of the direction of current flow; and (b) that it has a response proportional to the square of the current flowing.

Having thus described my invention and illustrated its use, what I claim is:

1. A wattmeter comprising two derived circuits each traversed by two superposed currents one of which is proportional to the voltage and the other to the amperage of the circuit the energy of which is to be measured, the said currents being additive in one of the circuits and opposed in the other, means associated with each of the said derived circuits for receiving and temporarily storing, during a definite time period, the energy effects therein, and means indicating the difference between the average stored

energy effects of the derived circuits, during said predetermined time period, substantially as described.

2. A wattmeter comprising two derived circuits each traversed by two superposed currents one of which is proportional to the voltage and the other to the amperage of the circuit the energy of which is to be measured, the said currents being additive in one of the circuits and opposed in the other, devices associated with each of the said derived circuits for receiving and temporarily storing the heat produced therein, means for adjusting the ratios of the thermal capacities of the heat-storage devices to the rate at which heat is radiated therefrom, and means for measuring the difference of the average heating effects of the derived circuits during a predetermined time period.

3. A wattmeter comprising two derived circuits each traversed by two superposed currents one of which is proportional to the voltage and the other to the amperage of the circuit the energy of which is to be measured, the said currents being additive in one of the circuits and opposed in the other, devices associated with each of the said derived circuits for receiving and temporarily storing the heat produced therein, means for measuring the difference of the average heating effects of the derived circuits during a predetermined time period, and integrating mechanism controlled by the said indicating means.

4. A wattmeter comprising two derived circuits each traversed by two superposed currents one of which is proportional to the voltage and the other to the amperage of the circuit the energy of which is to be measured, the said currents being additive in one of the circuits and opposed in the other, devices associated with each of the said derived circuits for receiving and temporarily storing, during a definite time period the heat produced therein, means for indicating the difference of the average heating effects of the derived circuits during a predetermined time period, and a maximum demand index actuated by the said indicating means.

5. A wattmeter comprising two derived circuits each traversed by two superposed currents one of which is proportional to the voltage and the other to the amperage of the circuit the energy of which is to be measured, the said currents being additive in one of the circuits and opposed in the other, two expansible bodies having adjustable time lag respectively heated by the currents traversing the said circuits, and an indicator actuated by the relative expansion of the said bodies.

6. A wattmeter comprising two derived circuits each traversed by two superposed currents one of which is proportional to the voltage and the other to the amperage of the

circuit the energy of which is to be measured, the said currents being additive in one of the circuits and opposed in the other, a plurality of actuating elements having adjustable energy-storing capacity differentially affected by the superposed currents in the said derived circuits, and means to indicate the average differential effects of the said superposed currents on the said actuating elements.

7. A wattmeter comprising two derived circuits each traversed by two superposed currents one of which is proportional to the voltage and the other to the amperage of the circuit the energy of which is to be measured, the said currents being additive in one of the circuits and opposed in the other, a plurality of actuating elements having definite and adjustable energy-storing capacity differentially affected by the superposed currents in the said derived circuits, means to indicate the average differential effects of the said superposed currents on the said actuating elements during a predetermined time period, and integrating mechanism controlled by the said indicating means.

8. A wattmeter indicator comprising a pair of expansion tubes with suitable conductors and heated by pairs of derived currents respectively proportional to the voltage and to the amperage of the circuit to be measured and superposed differentially in such conductors arranged for such heating, means to adjust the time lag of such heating, and means to continually indicate the condition of relative temperature of such tubes, substantially as described.

9. The combination with a pair of circuits traversed respectively by derived currents proportional to voltage and to amperage of the current to be measured, of a wattmeter indicator comprising two elements heated respectively by the added derived currents and by the derived currents mutually opposed, an indicator moved by the relative expansion of said elements during a definite time period and an integrating device in turn governed by said indicator.

10. The combination with a pair of circuits traversed respectively by derived currents proportional to voltage and to amperage of the current to be measured, of a watt-meter indicator comprising two expansion tubes having the ratio of their heat-storage capacity to their heat-dissipating capacity adjustable, and heated respectively by combining said derived currents and by opposing the derived currents, an indicator moved by the relative expansion of said tubes and a maximum demand index moved by the indicator.

11. A wattmeter indicator comprising two expansion elements heated respectively by a derived current proportional to voltage and a derived current proportional to am-

perage taken from the current to be measured, said derived currents acting in conjunction to heat one of said elements and in opposition to heat the other of said elements and means to introduce an adjustable time lag in the response of said elements without lessening the efficiency.

12. A wattmeter indicator comprising two corrugated tubes filled with liquid, electric conductors arranged to heat the liquid, a pivotally mounted movable pointer connected to the free ends of the tubes, an indicator, a motor therefor and gearing including a brush wheel connected to said pointer, whereby to govern the indicator by the movements of the pointer, substantially as described.

13. In a wattmeter comprising two heating conductors traversed by currents derived from the circuits to be measured and differentially heated thereby, a heat expansion device comprising a longitudinal expandible tube containing liquid and having a non-expandible portion of larger volume than the expandible portion, substantially as and for the purpose described.

14. A slow responding wattmeter comprising a heat absorbing element of adjust-

able capacity, an indicating device operated by the effect of such heat absorption, whereby the effect of energy absorption may be delayed for any desired predetermined time period.

15. A slow responding thermo wattmeter including a plurality of devices expanded by absorption of energy in the form of heat, means to indicate the relative expansion of said absorbing devices, and means to definitely fix and control the time lag of response, substantially as described.

16. A slow-responding meter comprising a pair of energy yielding elements, a pair of energy absorbing devices respectively associated therewith and adapted to receive and temporarily retain the energy absorbed therefrom, and means for indicating the difference between the average amounts of energy absorbed respectively by the said devices in a predetermined period of time.

In testimony whereof I have hereunto signed my name in the presence of the two subscribing witnesses.

PAUL M. LINCOLN.

Witnesses:

FREDK. STAUB,

JO. BAILY BROWN.