

Aug. 18, 1925.

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A. S. FITZ GERALD

THERMALLY CONTROLLED APPARATUS.

Filed May 17, 1923

6 Sheets-Sheet 1

Fig. 1.

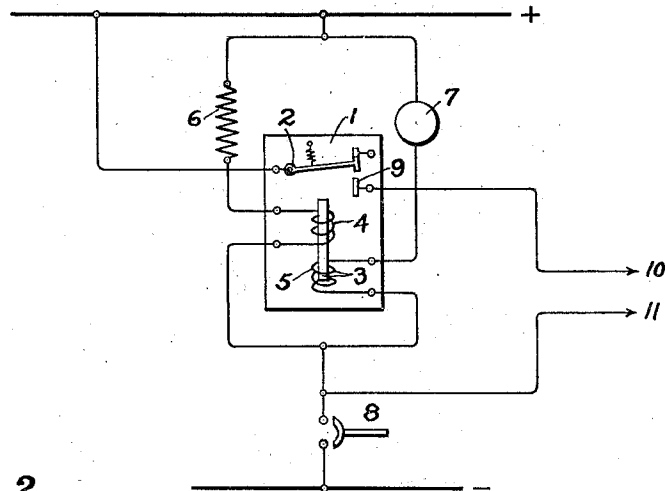
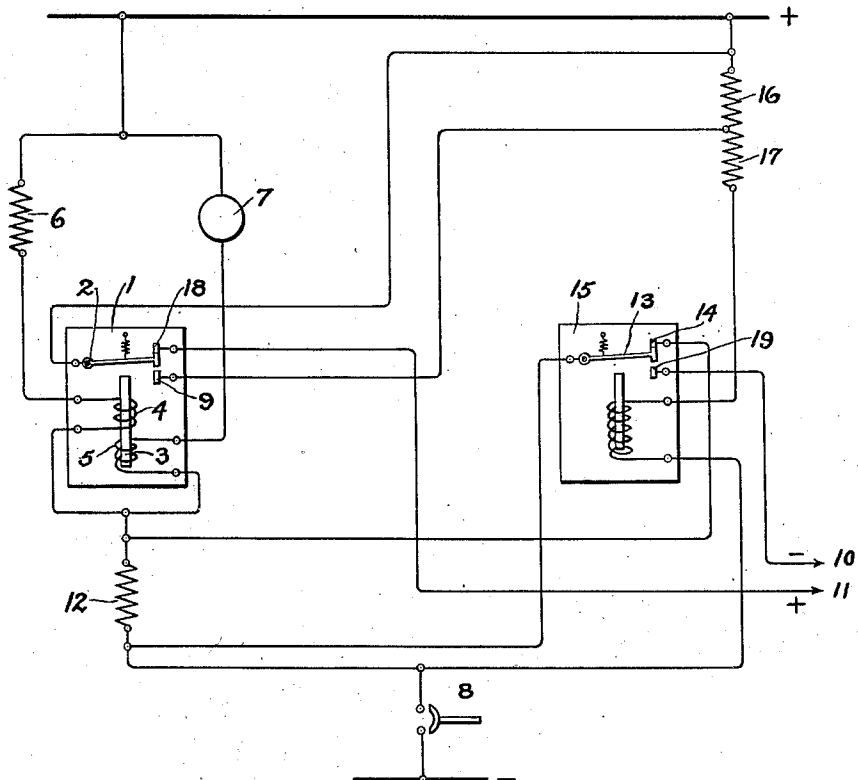


Fig. 2.



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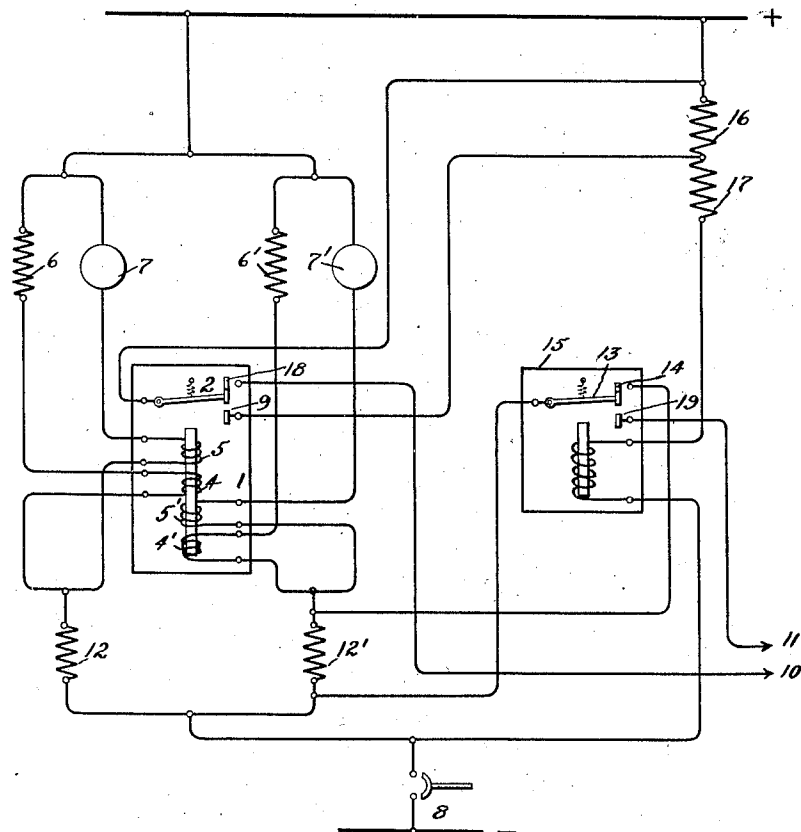
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6 Sheets-Sheet 2

Fig. 3.



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Fig. 4.

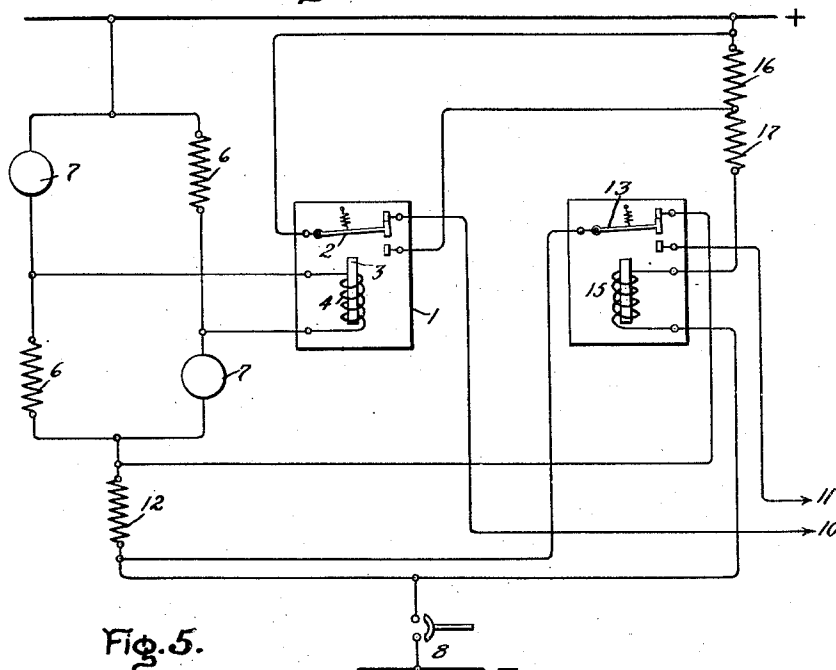
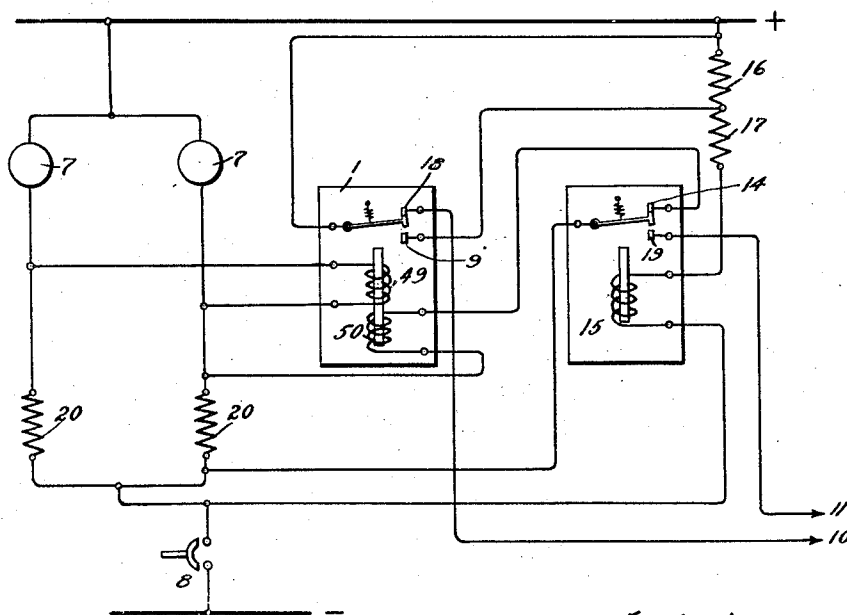


Fig. 5.



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Fig. 6.

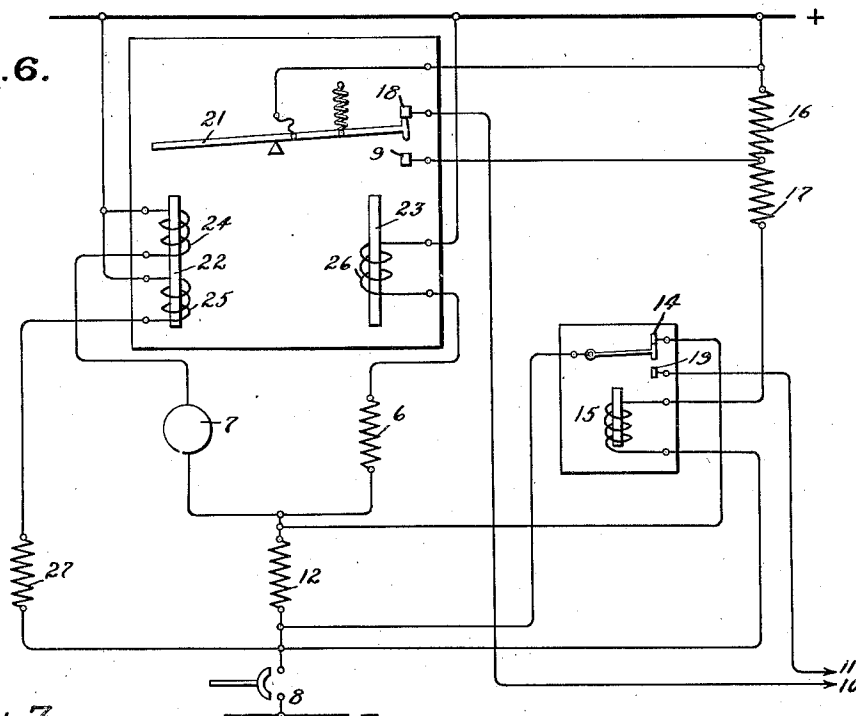
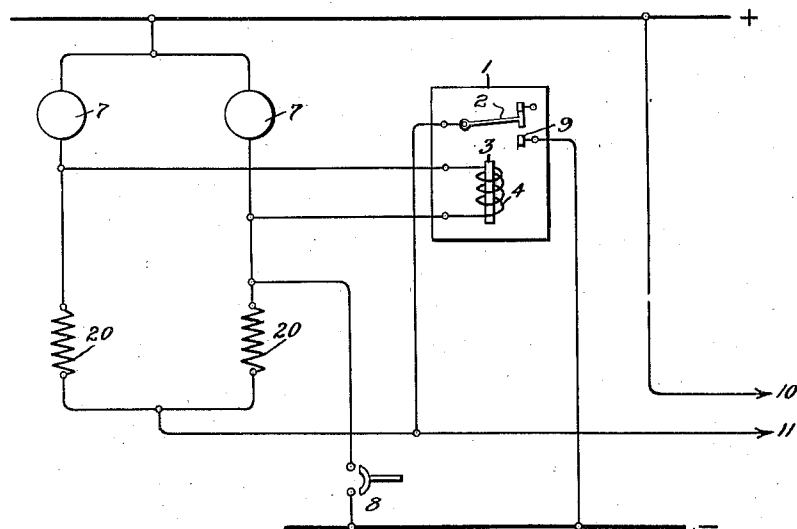


Fig. 7.



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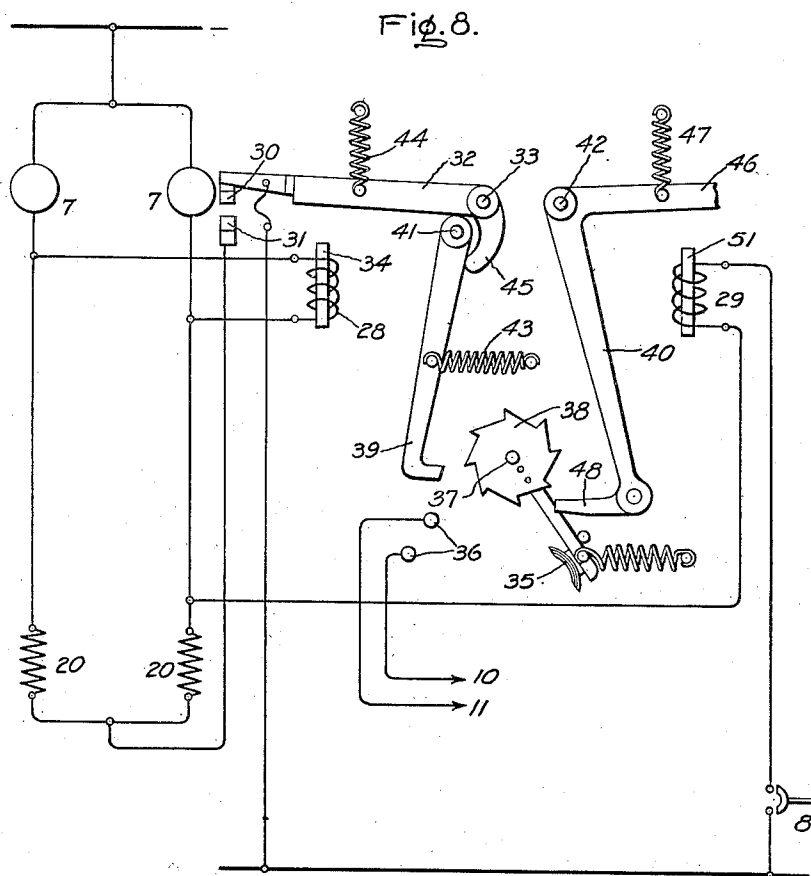
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THERMALLY CONTROLLED APPARATUS

Filed May 17, 1923

6 Sheets-Sheet 5



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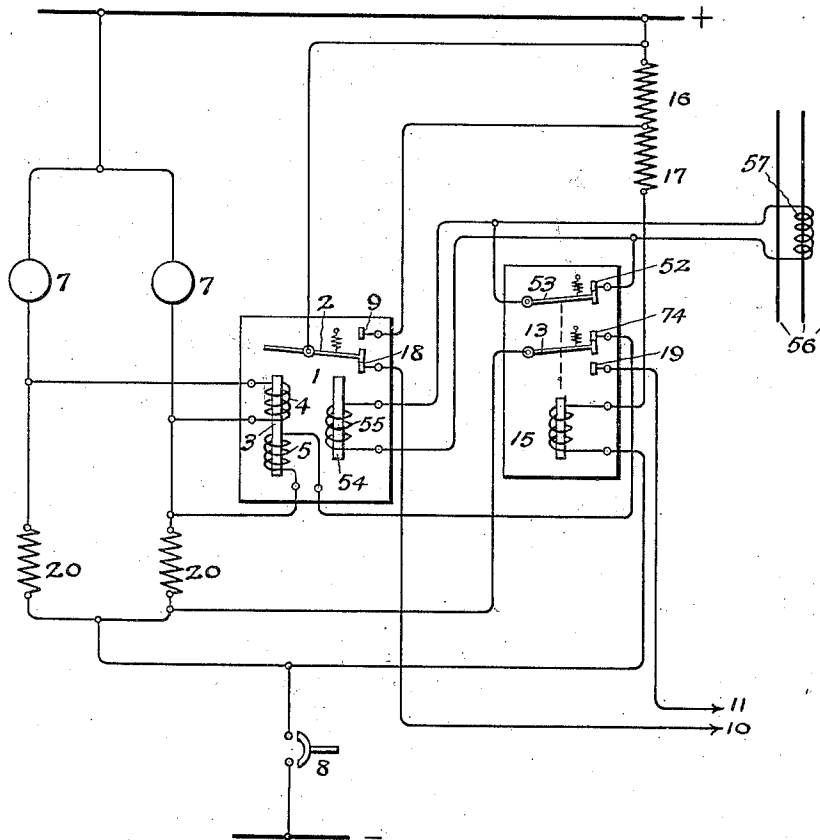
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Fig. 9.



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UNITED STATES PATENT OFFICE.

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THERMALLY-CONTROLLED APPARATUS.

Application filed May 17, 1923. Serial No. 639,626.

To all whom it may concern:

Be it known that I, ALAN STEWART FITZ GERALD, a subject of the British Empire, residing at London, England, have invented certain new and useful Improvements in Thermally-Controlled Apparatus, of which the following is a specification.

This invention relates to electric thermally controlled apparatus and systems employing the same, and particularly to thermal responsive relays which are intended to function after a predetermined lapse of time.

My invention is applicable to various purposes, but is more particularly intended to provide improved means for operating a relay under conditions involving considerable intervals of time of the order of minutes rather than seconds.

A further object of the invention is to provide an improved thermal responsive device which may be used as a time element switch or relay, or may be used for other purposes as well.

The design of time lag relays both of the definite time lag and inverse time lag varieties has in the past been commonly carried out on lines involving air or oil dashpots, bellows, or trains of clockwork, having either air vane or eddy-current escapement. It is found that the design of such relays presents no great difficulty when short time lags of the order of five seconds are required, but that when it is attempted to construct such a relay for delayed action of considerable duration the rate of displacement of its moving parts becomes so small that the element of friction is very detrimental to consistent operation, and that unless abnormally heavy actuating forces are employed the relay is liable to give capricious operation and even to fail entirely due to static friction.

In the present invention the use of frictional elements in determining the duration of the time lag is entirely avoided and in place of such we employ a thermo-responsive device caused to be heated from some suitable source, the time lag being arranged to depend upon both the rate of heating as well as the rate of cooling of the thermo-responsive device.

In carrying my invention into effect I may employ such devices as compound strip thermostats or the like, the preferred method, however, involving the use of a combined thermal and electrical effect, the ther-

mal device consisting of a winding or resistance which is heated from an extraneous source, and the electrical effect consisting of differential or other electrical circuits designed to function in a suitable manner, and being controlled by change in resistance of the said winding.

In order to provide a definite time lag thermal responsive relay in accordance with my invention, I arrange to heat the thermal element as readily as possible from some constant supply of energy, and on the same attaining any predetermined temperature rise, I cause the heating to cease, operation of the relay being arranged to occur when the temperature rise shall have fallen from the above to some lesser value suitably determined by the required conditions. Compensation for ambient temperature may be made in any desirable manner, examples being hereinafter described.

The invention is illustrated in the accompanying drawings in which Figures 1 to 9 show, by way of example and diagrammatically, several examples of circuit arrangements for carrying the invention into effect.

For a ready understanding of one of the underlying principles of operation of my invention, reference is first had to the arrangement shown in Fig. 1, in which a relay 1, having a spring controlled armature 2, a fixed core 3, and two windings 4 and 5, is employed. The two windings referred to are connected in such a way that equivalent currents flowing in the same direction from the source of potential act in opposition. The windings are connected in two parallel circuits, in one of which I have a resistance 6, which is constructed of resistance metal of the kind commonly employed in the building of rheostats and is notable for having a low or negligible temperature coefficient, while in the other branch of the circuit we connect a resistance 7 constructed of an element having a large positive temperature coefficient. The relative resistances of 6 and 7 are so arranged that at ambient temperature they are equal (or in such quantitative relation that the resultant excitation on the relay is zero if windings 4 and 5 be not of equivalent number of turns). If now the whole circuit be energized from a source of A. C. or D. C. power by the closing of the switch 8, the relay will not immediately operate, but current will flow through both

branches of the circuit. If the magnitude of this current be so arranged that appreciable heating of both 6 and 7 shall occur, the current will diminish in 7, and increase in 6 owing to the resistance of 7 increasing while 6 remains unchanged. It is assumed in this case that the supply of energy has constant current characteristics. The relay, therefore, will initially not be operatively excited, but afterwards will receive an operative excitation varying directly with time after the closing of the operating switch 8. When sufficient time has elapsed so that the excitation due to the difference between the ampere turns of coils 3 and 4 is of sufficient magnitude, the armature 2 will be attracted closing the contact 9, and causing terminals 10 and 11 to be energized across the source of potential.

Such an arrangement will function as an inverse time relay, that is the relay which operates in a period of time inversely proportional to the load on the apparatus.

It will be noticed that the actual duration of time for which the relay may be set is not definitely limited by the design or construction of the relay, as is the case in most of the more usual forms of time lag relay. By providing particular forms of resistance 7 more particularly described hereinafter, a given type of relay may be arranged to operate with short time lags or long time lags. The arrangement described in Fig. 1, however, has certain definite limitations, one of which is that it is dependent for its accuracy on its being operated from a constant voltage or current, and that errors will be introduced in accordance with such variation in the same which may occur.

A further requirement in connection with protective and other forms of definite time lag relay is that the relay shall at all times be in a position to provide exactly the specified time lag. It will be seen that the arrangement above described will only give the correct time lag if the actuating impulse occurs when resistances 6 and 7 are both at ambient temperatures. Should, however, the relay be energized and deenergized before the completion of the due period, it will not give correct operation should it immediately receive another actuating impulse, as the resistances 6 and 7 will already have become heated and therefore will not be balanced at the moment when the second actuating impulse commences. In these circumstances, therefore, repeated operation will cause inaccurate operation.

In order to overcome this latter difficulty, my present invention provides an arrangement in accordance with Fig. 2, in which similar parts are indicated with the same reference numerals and certain additional apparatus is shown. The relay 1 and resistances 6 and 7 are now connected as shown

in series with resistance 12, which latter resistance is arranged to be short circuited by the armature 13 when resting on contact 14 of a second relay 15, which, as in all other cases, is shown for convenience of illustration as operating downwards. Contact 14 therefore remains closed when the relay 15 is deenergized and resistance 12 is thus normally short circuited.

Relay 15, which is purely an auxiliary relay, is excited across the line in series with resistances 16 and 17, and is adjusted to have the following characteristic. If it is connected in circuit with 16 and 17 in series, it will not operate, but if operated by any means it will under these conditions remain closed. If the relay be excited with resistance 16 short circuited and therefore resistance 17 only in series, it will operate. The relay 15 resets when its coil is deenergized, that is, the armature contact comes to rest on contact 14.

According to this arrangement I arrange for resistance 16 to be short circuited by the relay 1 when energized to bring the armature on contact 9. It will be seen on referring to the diagram, that no part of the circuit can receive energy until the operating switch 8 is closed. On this being done, however, the circuit will be found in the following form.

Referring first to relay 15, this will be connected in series with resistances 16 and 17 and cannot therefore operate. Relay 1, however, and its accompanying resistance circuits will be closed across the line, resistance 12 being short circuited, and under these conditions, it is arranged to take a sufficiently heavy current to cause heating of the resistance 7. This latter is designed for this particular requirement to heat very rapidly, and may be arranged to do this within a period of the order of 1% of the total time lag over which the relay is to operate. Immediately following the closing of switch 8, therefore, there will be a rapid change of resistance and a corresponding unbalance excitation occurring due to the windings 4 and 5, which will cause operation of the armature 2. This will close contact 9, short circuit resistance 16, and cause immediate operation of the relay 15, whose armature 13, closing on to its bottom contact 19, will cause resistance 12 to be placed in circuit. The magnitude of this resistance 12 is so arranged that when this latter condition obtains, sufficient current flows in 6 and 7 to enable the relay to function in accordance with the relation between these two currents, but is not sufficiently strong to raise the resistance 7 to a temperature very much in excess of the ambient temperature. Directly, therefore, resistance 12 is placed in circuit, resistance 7 commences to cool. After due elapse of

time the resistance of 7 will again approximate to the resistance 6, it being noted that 6 and 7 are arranged to balance cold as in Fig. 1, and this having occurred, there will be no resultant excitation due to windings 4 and 5, and the armature 2 will rise, opening contact 9. Throughout this period, however, armature 13 of relay 15 will have remained attracted, and contact 19 will have been made. This will still obtain when contact 9 is opened, as this will leave relay 15 energized in series with 16 and 17, under which condition, it has been postulated, the relay 15 will retain its armature 13. Therefore, immediately following final deenergization of the relay 1, there will be a complete circuit between the positive source of power, the terminals 10 and 11, the operating switch 8 and the negative source of power. Such tripping or other apparatus as may have been connected to 10 and 11 will be operated. At no previous stage in the sequence of operation can this complete circuit have been made. Should now an operation occur which is not completed, it will be seen that the error of repeating will be reduced to a minimum as it has been postulated that the characteristic of the resistance 7 is such that heating occurs very rapidly in comparison with the time of cooling. On a rapid operation, therefore, such error as may occur will be confined to the brief heating period. The cooling curve which determines the whole, with the exception of a small percentage, of the time lag, will remain unaltered at no matter what temperature the resistance 7 may be at the instant when the actuating impulse is received by the operation of switch 8. In the practical application of this embodiment of the invention, switch 8 may be an overload, protective or other form of relay or electroresponsive device. It will be further noted that the terminals 10 and 11 can only be energized if the switch 8 be held closed for the whole period of time lag for which the relay is set, and that, as stated in discussing the question of repetition, a repeated operation immediately following will be unaffected by a previous partially completed cycle.

Attention was drawn above in consideration of Fig. 1 to the fact that a definite time lag can only be obtained by the arrangement of connections shown therein, if the circuit be operated at constant current or constant potential. The same limitation will apply to a less extent to Fig. 2, and whereas it may in many cases be possible to get satisfactory operation where the source of energy is a battery or some other constant supply, it is possible by employing an arrangement as shown in Fig. 3 to compensate for such error as may occur due to variations in the supply line voltage.

In order to achieve this, I provide an exactly similar circuit with the exception that I duplicate resistances 6, 7 and 12, and windings 4 and 5. Thus, the resistances 6' and 7' are provided for controlling the windings 4' and 5'. The one winding 4' is wound in the opposite sense to the other winding 4, similarly with the two coils 5 and 5'. It is to be noted, however, that only the resistance 12' is cut out by the relay 15. By this arrangement exactly similar operation will be arrived at to that obtained in Fig. 2, which it will not be necessary to describe again. The characteristics, however, introduced by the additional resistances and windings are such as to compensate for differences in the line voltage, and also for differences in the ambient temperature.

It should be explained with reference to compensation for variations in line voltage (Fig. 2), that such errors as occur are due to the change which necessarily takes place in the resistance of 7, under what is referred to as "cold" conditions, with change of line voltage. By the term "cold" condition, is meant a state of affairs in which resistance 12 is in circuit, and only a small current flows in the resistances 6 and 7, and in the relay 1. It is found that the ratio of the two small currents flowing in 6 and 7 under "cold" condition are appreciably altered by small changes in the line voltage, but that by the duplicate circuits employed in Fig. 3, this effect which occurs accordingly in duplicate, may be eliminated or balanced out.

With regard to ambient temperature, it is found in practice that by arranging resistances 7 and 7' in such physical form that they may operate over a range of many hundred degrees centigrade, any error due to ambient temperature cannot be appreciated, but the compensating feature is present and may be utilized if the operating range be less.

Figs. 4, 5, 6 and 7 show arrangements for providing similar characteristics to Figs. 2 and 3 in slightly different manners. The circuit shown in Fig. 4, which is a counterpart of Fig. 2, employs exactly the same cycle of operations, but employs two resistances 7 and two resistances 6, and is arranged to give operation with a relay 1 provided with only one winding. This arrangement, however is not compensated for voltage. If, however, the connections shown on Fig. 5 be employed, it is possible, utilizing a relay having two windings instead of four, as is the case in Fig. 3, to retain the characteristics of the scheme shown in Fig. 3 with reference to ambient temperature and variations in voltage.

In this latter case it should be noted that resistances 20 are employed which perform

a function analogous both to that of resistances 6 and resistances 12, one of the resistances 7 and its corresponding resistance 20 operate always under "cold" conditions, and the presence of these latter is purely in the interest of compensation, as described. The other resistance 7 is caused to become heated when its corresponding resistance 20 is short circuited in a similar manner to the effect occurring when resistance 12 is short circuited in Fig. 2. With the latter resistance 20 in circuit, however, a complete balance bridge arrangement is arrived at. It should be noted with regard to the schemes employed in Figs. 4 and 5, that the resistance of the relay windings should have such relation to the resistances 6, 7, 20, etc., as to give the most efficient operation if the circuit be considered as a form of Wheatstone bridge, the principle of which it does in fact follow.

The resistance, therefore, of the winding 49 should be large with regard to 7 and 20. This winding may be regarded purely as the resistance measuring coil, performing the same function as the single winding shown in Fig. 4.

The additional winding 50 is provided for the following reason. In the absence of 50 it will be observed that the winding 49 becomes excited due to unbalance immediately the resistance 20 is short circuited. It is required, however, and arranged for in previous diagrams that there should be a definite heating period, this being controlled as explained by the temperature of 7.

The winding 50, therefore, during the heating period is arranged to provide ampere turns equal to and opposite to the excitation provided in 49 when 20 is short circuited and when no heating of 7 has yet taken place. This counter-excitation, however decreases as heating of 7 occurs, and the relay operates when 49 preponderates to the necessary extent.

Operation of the relay, therefore, as heretofore occurs at a predetermined temperature of 7.

Following operation of the relay 1 and relay 15, however, the coil 50 is no longer energized and the relay functions as a resistance measuring device during the cooling period as in previous arrangements.

The above diagram constitutes the preferred form of the invention for a definite time lag relay.

Fig. 6 shows an alternative arrangement, capable of even greater precision, with which object in view a balanced beam type of relay may be employed in place of a plain attracted armature. This arrangement is capable of even more accurate results than those previously described, which latter, however, are in general preferable owing to their simplicity.

In this connection it should be noted that the function of relay 15 operating in conjunction with resistances 16, 17, etc., is precisely as previously described. In this case, however, relay 1 is provided with a balance beam 21, fixed cores 22 and 23 and windings 24, 25 and 26, the effect of cooling of this arrangement causing, as heretofore, decrease of the current in 6, and increase of the current in 7. This will cause the pull due to coil 26 to decrease with regard to the pull in coil 24, causing operation in a similar manner to that described in Fig. 2 and those following. The arrangement shown in Fig. 6, however, is compensated for voltage variation by the provision of an additional winding 25, operating in series with 16, 17 and the winding of relay 15, and an additional resistance 27. The nature of the discrepancy set up by a change in line voltage has been previously described; and the effect of winding 25 is to introduce an effect, most easily determined by experiments, having regard to the thermal characteristics of 7, which is arranged to be equal and opposite to the discrepant effect. The extent of the compensation which can be obtained by this and the other methods described, is of the order which makes it possible to satisfactorily operate such a relay with an error not exceeding 5% with a change in voltage of + or - 20%. It is of course understood that the perfection of the compensation depends to a large extent on the precision of the relays and apparatus involved, but the above figures may be taken to be commercial results.

In the foregoing diagrams I have described various methods of carrying into effect definite time lag action in which a circuit may be closed or by a different arrangement opened at a predetermined interval after a controlling switch 8 is actuated.

According to another modification I show in Fig. 7 an arrangement such as is frequently met with in protective devices and control diagrams in which the time lag is arranged to occur subsequent to the opening of the control switch 8.

In Fig. 7, I employ resistances 7 and 20, and relay 1, otherwise as in previous diagrams. It will be noticed that relay 1 has now the armature 2 and core 3, as before, but has only one winding 4 and one contact closed when 4 is energized.

The operation will now be as follows:

On closing switch 8 relay 1 will operate instantly due to the fact that one of the resistances 20 is short circuited, and there is initial out of balance current flowing in its winding, and will complete the circuit through the terminals 10 and 11.

In this case, as distinct from the case shown in Fig. 5, what is described as the heating current is arranged to be carried

continuously. Switch 8, therefore, will be closed for an indefinite period, but resistance 7 will, a brief interval after the closing of 8, have attained a final steady temperature, and this will be maintained so long as switch 8 is closed. Immediately, however, switch 8 is opened the heavy current sufficient to maintain 7 at its hot temperature, ceases, and there flows instead what has been previously described as the measuring current. Due to the lack of balance between the hot resistance 7 and the cold resistance 7, however, relay 1 will not open immediately 8 is opened but will continue to energize 10 and 11 until such time as the two resistances 7 are sufficiently in balance to allow the armature 2 to open the contact when the relay operating circuit is completely opened, at the same time energy being cut off from 10 and 11. It is to be noted that this arrangement is compensated as described with regard to Fig. 5, both for variations in operating voltage and for change in ambient temperature should this be comparable with the operating temperature of the hot resistance 7.

In Fig. 8 we show the application of this thermal principle to a relay such as is commonly described as a "notching" relay, this being the term given to the form of relay which is frequently employed in connection with auto-reclosing apparatus, and having the following characteristics:

The relay is arranged to close or open its circuit as may be required, not when the relay is energized, but only after the relay has been energized and the circuit broken a given number of times in succession within a given interval. To achieve this, it is common to employ a time lag element and a notching mechanism such that the contacts can only be operated when a given number of notches have been effected. The time lag element is introduced on the relay being deenergized, so that the relay in effect has a time lag reset characteristic which is arranged to release a latch on the notching mechanism a given time after the relay has been deenergized. Operation, therefore, of the contacts can only be achieved if all the notches are taken before the relay can reset.

In Fig. 8, I show resistances 20 and 7 as heretofore and a special form of relay having windings 28 and 29, a movable contact 30 and a fixed contact 31 the movable contact 30 being mounted on the end of an armature 32, which is pivoted on 33, and arranged to be attracted by core 34 when coil 28 is energized to the necessary extent.

Armature 32 is restrained by spring 44, the contacts 30 and 31 being normally opened therefore unless coil 28 is energized. The main contact 35, which when bridging contacts 36 closes a circuit between termi-

nals 10 and 11, is attached to a spindle 37 on which is mounted a ratchet wheel 38. In this instance the contacts 35 and 36 are arranged to close an entirely separate circuit which is not shown, i. e., they do not energize the terminals 10 and 11 from the same supply from which the relay draws its operating energy.

Two levers 39 and 40 are pivoted respectively at 41 and 42 the former being constrained by spring 43, to move towards the ratchet wheel 38.

Lever 39 is constructed of such a shape as to form a latch engaging on the teeth of wheel 38, when it is permitted to do so by the projection 45 on the lever 32, which is arranged so that this only occurs when coil 28 is energized.

When coil 28 is deenergized, the relative strength of springs 43 and 44 are so arranged that latch 39 releases wheel 38. Thus the releasing value for 32 is independent of friction between latch and tooth.

The lever 40 pivoted at 42, is made integral with the armature 46 which is attracted by the core 51 when excited by coil 29, and is provided with a pivoted catch 48 arranged to engage with the teeth of the wheel 38, so that when 29 is energized, wheel 38 moves through one tooth pitch. On coil 29 being deenergized, wheel 38 is constrained by a spring not shown, to return to its original position unless coil 28 is energized, in which case it will be retained in the position which it has assumed due to the movement of lever 40. Movement of armature 46 to the attracted position is resisted by spring 47.

The operation of the complete arrangement is as follows: On the closing of switch 8, winding 29 becomes energized, attracting 46 and causing heating of one of the resistances 7 followed by the energization of winding 28, causing operation of armature 32 and lever 39, due to the unbalancing effect. If switch 8 is now opened, lever 40 will recede, but lever 39 will continue to engage with a tooth on wheel 38. Assuming that switch 8 is not reclosed, one of the resistances 7 (the hot one) slowly cooling, will cause the circuit comprised by the circuit resistances 7 and 20—to become more and more balanced, causing in consequence the current in 28 to be correspondingly reduced. In due course, therefore, 28 will no longer retain the armature 32 causing the contacts 30 and 31 to open, at the same time constraining lever 39 to release 38. If on the other hand, switch 8 had been closed a second time before the release of 38 after the manner described, a second operation of 40 would have occurred, causing another tooth of 38 to be engaged.

It will be seen therefore that in accordance with the setting of the notching mecha-

nism, a number of consecutive operations of switch 8 will finally cause the contacts 36 to be closed by the bridge piece 35, providing that there does not elapse after each opening of 8 an interval of time greater than that necessary for the resistance circuit to become balanced and the coil 28 to be de-energized, in which case 38 always returns to the starting position owing to the action of its return-to-normal spring.

In all the previous diagrams I have shown various methods of providing definite time lag effects; in connection with protective circuits however it is commonly required to provide a time lag inversely proportional to the magnitude of a current, overload, etc., and in Fig. 8 I show after what manner this may be achieved. In this case it is assumed that a source of operating energy is available for operating the mechanism of the relay distinct from the current according to the magnitude of which I wish to control the time lag.

In Fig. 9 I employ resistances 7, 16, 17, 20, etc., as in Fig. 5, and relays 1 and 15. Relay 1 is provided with windings 4 and 5 having functions precisely as specified hereinbefore. Relay 15 is also provided with a winding exactly as described in Fig. 5. Relay 15, however, is provided with an additional stationary contact 52 and a movable contact 53, mechanically coupled to or mounted on its armature, and arranged to open circuit when relay 15 is operated.

The armature 2 of relay 1 is now pivoted centrally, but has the same contacts as in the previous diagrams. The magnetizing effect due to 4 and 5 is arranged to provide exactly the same operation as in Fig. 2 and onwards. In Fig. 9, however, contacts of Fig. 1 will be shown upside down as compared with previous diagrams, for the sake of convenience, as the extremity of armature 2 is now moving in the opposite direction when attracted by the core 3. On the opposite side of the fulcrum on which the armature 2 pivots, we provide an additional core 54 excited by a winding 55. To the right of the diagram I show three conductors 56 representing for the sake of example, a three-phase circuit. On one of these conductors I show a current transformer 57, whose secondary is arranged to excite the winding 55.

Core 54, therefore, will attract the armature 2, with a force depending on the strength of the current flowing in the three-phase circuit 56. It is to be noted that the spring or other restraining effect which though not shown is understood to control 2, is arranged to constrain 2, to assume the position shown on the diagram, and it will be seen that the effect of core 54 is to assist such action. If, therefore, the whole diagram be considered to operate as a definite

time lag relay, entirely as described with regard to diagram 5, it will be recalled that during the cooling period the contact on the end of 2 will be closed on the upper fixed contact and during this period, the force due to the restraint of 4 and 5, will be slowly decreasing. When this resultant force no longer exceeds the resetting effort of the spring or controlling means, the armature moves downwards closing on to its bottom contact, and completing the circuit to 10 and 11. It will be clearly comprehended, therefore, that if the effect of coil 55 is to assist the controlling means, it will due to this fact, shorten the period of time lag, and by suitably designing the winding 55, the actual duration of the time lag may be made inversely proportional to the strength of the current 56.

It is to be noted, however, that the excitation due to coil 55 should not interfere with the heating period, as in the event of a very heavy current in coil 55 it might preclude the armature 2 lifting off the bottom contact in order to stop the heating when the resistance 7 has attained a certain temperature.

For this reason, therefore, I have shown the contacts 53 and 52 mounted on the relay 15, which are arranged to short circuit the current transformer 57 during the heating period, only energizing the coil 55 on the commencement of the cooling period. It is to be noted, therefore, that even should the current in the load circuit 56 be excessively high due to a severe short circuit, the armature 2 will carry out its normal heating cycle, which in practice would be of the order of a fraction of a second, and that immediately on the operation of relay 15 it would due to the very high excitation of coil 55 immediately return to the bottom contact. This gives the arrangement the characteristic of a definite minimum time lag since no matter how heavy may be the current in the load circuit, the heating cycle must be carried out following by instantaneous operation of the relay 15 and the return movement of contact 2.

With regard to the resistances 7 referred to throughout the specification, I have found excellent results for time lags up to half-minute to be given by tungsten wires mounted in vacuo or in a noble gas after the manner of incandescent lamps. I find, however, the operation in vacuo to be superior to that in gas with reference to the desirability of a definite time lag relay giving exactly the same time lag in the event of several consecutive operations being made. It has been noted in the case of gas-filled bulbs that after three or four operations a slight error is introduced which is due to the heating of the gas surrounding the tungsten wire.

It is not essential that the resistance which

varies with the temperature should have a positive temperature coefficient as materials such as boron with a negative temperature coefficient may also be used with corresponding modification of the balancing circuits. I prefer however to use the positive temperature coefficient of a metal such as tungsten because this metal is readily obtainable in the form of wire with the same characteristic properties in different batches. Moreover its high melting point permits of a wide range of temperature variation being used. The tungsten resistance enclosed in an evacuated bulb may be operated at a temperature such that the life of the device will be much beyond the thousand hours average aimed at in lamp manufacture. In order to slow down the rate of cooling the resistance may be shrouded by a cup or other suitable form of heat storage arrangement.

What I claim as new and desire to secure by Letters Patent of the United States, is,—

1. A time element circuit controlling device comprising a movable controlling member capable of two movements, thermal responsive means subject to different temperature conditions, means whereby the controlling member is given one of its movements a time interval after the thermal means is subjected to one temperature condition and is given the other of its two movements a time interval after said means is subjected to a different temperature condition, and switch mechanism and connections whereby the circuit controlled by the device is energized only after the said controlling member has performed each of its two movements.

2. A time element circuit controlling device comprising a movable controlling member capable of two movements, thermal responsive means for giving the controlling member one of its two movements a time interval after the thermal means is subjected to a predetermined heating effect and for giving the controlling member the other of its two movements a time interval after a predetermined reduction in the heating of said thermal means, means controlled by said controlling member and cooperating with said thermal means for reducing the heating thereof, and switch mechanism and connections whereby the circuit controlled by the device is energized only after the said controlling member has performed each of its two movements.

3. A time element circuit controlling device comprising thermal responsive means having a controlling member operable between two positions responsively to predetermined variations in the temperature of said means, means for electrically heating said thermal responsive means to operate said member from the first of said positions to the second of said positions, means con-

trolled by said member for controlling the said electrical heating means to effect the return of said controlling member to the first position, and switch mechanism and connections whereby the circuit controlled by the device is energized only after the said controlling member has been operated to said second position and returned to said first position.

4. A time element circuit controlling device comprising thermal responsive means having a circuit controlling member operable to one position when the temperature of said means is at one value and to a second position when the temperature of said means is at another value, electroresponsive means controlled by said member in said second position and cooperating with said thermal responsive means for controlling the heating thereof to return said member to said one position, and connections whereby the said circuit controlling member is required to move to said second position and then return to said one position under the control of said electroresponsive means prior to energization of the circuit controlled by the device.

5. A time element circuit controlling device comprising thermal responsive means having a circuit controlling member operable with a time delay to and from a circuit controlling position responsively to variations in the temperature of said means, an auxiliary switch cooperating with said member to jointly control a circuit, means whereby said auxiliary switch is operated to control the circuit, a time interval after the operation of said member from said circuit controlling position, and means for controlling the temperature of said thermal responsive means to return said member to said circuit controlling position a time interval after the operation of said auxiliary switch.

6. A time element circuit controlling device comprising thermal current responsive means having a circuit controlling member operable with a time delay to and from a circuit closing position responsively to predetermined variations in the energizing current thereof, an auxiliary switch connected in series with said member to jointly control a circuit, means whereby said switch is closed a time interval after the operation of said member from said circuit closing position, and connections for controlling the energizing current of said thermal responsive means to return said member to said circuit closing position a time interval after the closure of said auxiliary switch.

7. A time element circuit controlling device comprising electrically heated thermal responsive means having a circuit controlling member operable from a circuit controlling position to another position respon-

sively to a predetermined heating effect, an electroresponsive switch cooperating with said member to jointly control a circuit, and connections whereby said electroresponsive switch is operated to the circuit controlling position upon the operation of said member to said other position and the heating of said thermal responsive means is controlled to return said member to the circuit controlling position a time interval after the operation of said switch.

8. A time element circuit controlling device comprising a movable switch member biased to a circuit closing position, electrically heated thermal responsive means for operating said member from said circuit closing position to a second position a time interval after the application of a predetermined heating effect to said means, an electromagnetic switch connected to be controlled by said member and arranged to be operated to a circuit closing position upon the operation of said member to said second position, connections whereby the heating current of said thermal responsive means is decreased upon the operation of said electromagnetic switch to said circuit closing position to permit said movable switch member to return to the circuit closing position, and connections whereby the circuit controlled by the device is energized only when said switch member and said electromagnetic switch are in their respective circuit closing positions.

9. A time element thermal responsive device comprising a pair of circuit controlling members each operable between two positions and biased to one of said positions, electrically heated thermal responsive means for operating the first of said members from the biased position to its other position responsively to the heating effect of a predetermined current, electroresponsive means controlled by said first member in said other

position for operating said second member from the biased position to its other position and for maintaining the same therein, and means controlled by said second member for reducing the heating current of said thermal responsive means to permit said first member to return to the biased position a time interval after the operation of said second member to its other position, and connections whereby the circuit controlled by the device is energized when the first of said members is in its biased position and the second of said members is in its other position.

10. The combination in a time element switch of a switch member, electroresponsive means for controlling the said switch member, a resistor having an appreciable temperature coefficient, a multiple connected resistor having a materially lower temperature coefficient, the said resistors connected in a circuit to be heated responsively to the current therein and arranged to control the said electroresponsive means responsively to the difference in the resistance of the said resistors due to heating thereof, auxiliary switch mechanism controlled by the said switch member, and a resistor in the circuit of the said multiple connected resistors under the control of the said auxiliary switch mechanism for controlling the heating of said multiple connected resistors.

11. A time element switch as specified in claim 10, characterized by the fact that an additional set of multiple connected different thermal coefficient resistors are provided and connected in multiple relation with the multiple connected resistors specified in claim 10, so as to compensate for changes in ambient temperature and operating current or potential.

In witness whereof, I have hereunto set my hand this seventh day of May, 1923.

ALAN STEWART FITZ GERALD.