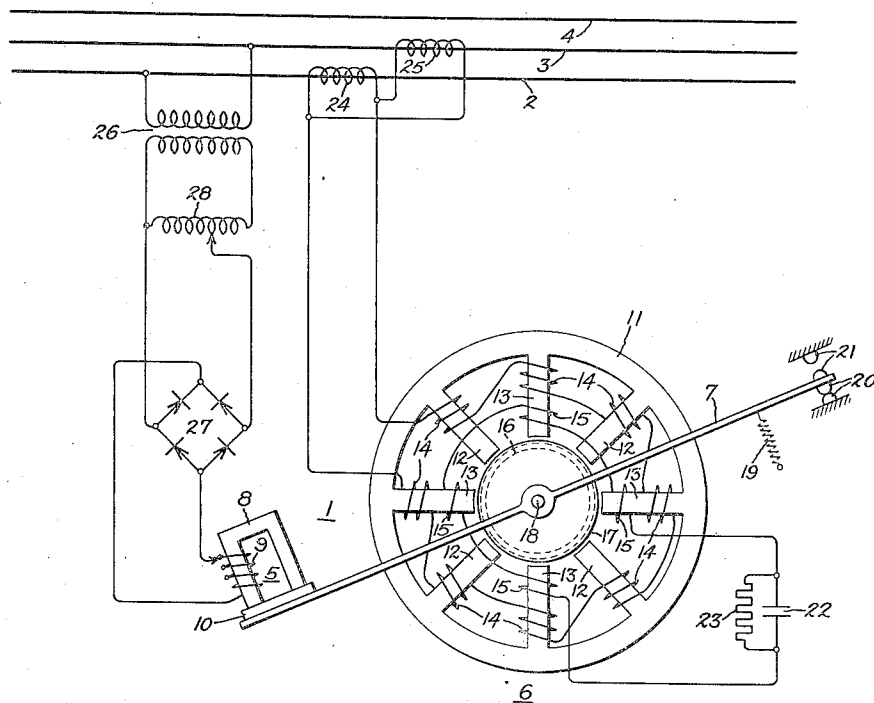


2,352,985

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Inventor:
Albert R. van C. Warrington,
by *Harry E. Dunham*
His Attorney.

UNITED STATES PATENT OFFICE

2,352,985

ELECTRORESPONSIVE DEVICE

Albert R. van C. Warrington, Wallingford, Pa., assignor to General Electric Company, a corporation of New York

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9 Claims. (Cl. 175-294)

My invention relates to improvements in electro-responsive devices which function in accordance with a comparison of two effects respectively dependent on two different alternating current quantities and more particularly to improvements in impedance relays, and especially high speed impedance relays, which function in dependence on a predetermined relation between a voltage and a current of an alternating current circuit.

Certain so-called distance relays are intended to function when, as in case of a fault, the circuit impedance Z is less than the relay setting or pickup point Z' . It is usual to try to obtain this impedance response by the comparison of two effects respectively dependent on the voltage E and the current I of the circuit with the idea of getting a relay action based on the ratio of the effective value of the voltage to the effective value of the current, that is,

$$\frac{E}{I}$$

which equals Z . In other words, the pickup response Z' would be constant and would depend only on the ratio

$$\frac{E}{I}$$

regardless of the magnitudes of E and I . Generally, this is attempted by the use of two electromagnetic devices arranged to control the actuation of a circuit controlling member by two opposing torques or forces, or the like, which are respectively dependent on the circuit voltage and the circuit current so that at the balance point where relay operation occurs, these effects are substantially equal. These effects may be expressed in terms of E and I and constants K_1 and K_2 as follows:

$$K_1 E^m \text{ and } K_2 I^n$$

Equating these functions for the balance point gives

$$\frac{K_1}{K_2} = \frac{E^m}{I^n} = (Z')^n E^{m-n}$$

If the exponents m and n were equal, regardless of the effective values of E and I throughout the range of operation of the relay, then at the balance point the ratio

$$\frac{K_1}{K_2}$$

would always equal Z' raised to the common value m and n since the factor E^{m-n} would be unitv. Consequently the relay would always respond to any impedance value below this value Z' . The-

oretically, all that it is necessary to do is to provide two electromagnetic means whose functional characteristics are respectively dependent on E and I raised to the same power and to have the voltage effect independent of cyclic variation in order, in case of high speed relays, to prevent false action in consequence of such cyclic variation. Of course, if two electromagnetic devices having substantially identical characteristics throughout their operating range were used to provide the two effects, and if each were independent of cyclic variation of the alternating current quantities by which they are energized, the desired impedance response could be obtained.

In a high speed impedance relay, the requirements for the current or operating element are high speed, immunity to D. C. offset and other transients, and steady action throughout the cyclic variation of the current. The induction cylinder relay satisfies these requirements. The potential or restraining element should have low burden in order to permit operation on short lines and not to interfere with the accuracy of potential transformers. In order to obtain uniform impedance response at all values of current, it is necessary that the current and potential elements have matched characteristics, that is, effects such as torques, for example, which are proportional respectively to E^n and E^m , where m equals n . The easiest way of doing this is to use the same construction for both elements. However, the induction cylinder device does not have a very high torque for a given volt-ampere input so that it is not suitable for the restraining or potential element of an impedance relay. The clapper or hinged armature type of magnetic element is highly efficient, but it has a torque proportional to E^m , where m is between 1 and 2. The induction cylinder has a torque proportional to I^n , where n equals 2. For applications not requiring great accuracy of ohmic measurement, this difference may be acceptable, but in devices like the ohmic unit of a distance relay, the torques must be matched.

A further necessary feature of impedance relays is that they should have the same ohmic pickup for any phase angle between the voltage and the current. Prior impedance relays have used rectification or phase splitting in their potential circuits to give a substantially constant pull so that the pickup of the relay would be the same at any phase angle between E and I . In practice, however, it is not possible so to design phase splitting circuits that the torque of the magnet will vary less than $\pm 20\%$. It is also im-

portant in impedance relays to have a high dropout so that they will not remain in the actuated or response condition during power swings that often follow a fault. In prior balanced beam type relays, the dropout is around 60% of the pickup and varies greatly with the phase angle between the current and the load.

An object of my invention is to provide an improved high speed electroresponsive device having a characteristic which is dependent on the ratio between two alternating current electric quantities and independent of the phase angle between them. Another object of my invention is to provide an improved high speed impedance relay which is not responsive to offset and transient currents and which has a low potential burden and yet possesses a low ohmic pickup. A further object of my invention is to provide an improved high speed impedance relay having an ohmic response which truly reflects the ratio of a circuit voltage to a circuit current and which is substantially unaffected by cyclic variation of either the current or the voltage. A still further object of my invention is to accomplish the foregoing objects with a relatively simple and practical structure whose cost is not economically prohibitive. These and other objects of my invention will hereinafter appear in more detail.

In accordance with my invention, I provide an improved high speed electroresponsive device comprising two different electromagnetic units which are respectively energized by two different alternating current electric quantities and which cooperate in controlling the movement of a circuit controlling member in dependence on the ratio between the two quantities and independently of the phase angle between them. Likewise in accordance with my invention, I choose two different types of electromagnetic units having different operating characteristics and then so modify the characteristic of one of the units that their resultant operating effect on the circuit controlling member is a true reflection of the ratio between the two alternating current quantities. Also in accordance with my invention, the operation of one of these units is independent of cyclic variation of the alternating current quantity by which it is energized, and the other unit may also be made independent of the cyclic variation of the alternating current quantity by which it is energized as desired. Further in accordance with my invention, my electroresponsive device, when one of the electromagnetic units is energized by a voltage of the circuit and the other unit is energized by a current of the circuit, constitutes an improved high speed impedance relay having a low ohmic response with low potential burden. Still further in accordance with my invention, the two electromagnetic units constitute an improved high speed impedance relay whose response is substantially unaffected by offset and transient currents.

Again in accordance with my invention, I use a current responsive or operating element which has such a substantially constant torque throughout the cyclic variation of the current that the pickup is not affected by the phase angle between the current and the voltage. Also in accordance with my invention, I use a potential or restraining element whereby the pickup may be closely adjusted by varying the size of the gap of the potential magnet and the dropout may be made as high as 95% of the pickup.

My invention will be better understood when considered in connection with the accompanying

sheet of drawings, and its scope will be pointed out in the appended claims.

In the single figure of the accompanying drawing, I have illustrated an embodiment of my invention in the form of an electroresponsive device, such as a high speed impedance relay 1, so connected as to respond to an interphase fault involving the phase conductors 2 and 3 of a three-phase alternating current electric circuit comprising phase conductors 2, 3 and 4. It will be understood by those skilled in the art that the relay 1 may be arranged to control the operation of suitable circuit interrupting means, not shown, in the circuit 2, 3, 4 either directly or in conjunction with other relays. As illustrated, the relay 1 comprises two different electromagnetic means or units 5 and 6 which, in accordance with my invention, have different operating characteristics and which are arranged to exert on a rotatably mounted circuit controlling member 7 opposing effects, such as torques respectively dependent on a voltage and a current of the circuit 2, 3, 4.

In accordance with my invention, the electromagnetic unit 5 is so chosen as to have a low potential burden. For this purpose, it may be of the movable magnetic armature type illustrated. As shown, the unit 5 comprises a U-shaped magnet 8, an energizing winding 9, and a magnetic armature 10, which is mounted to partake of the movement of the circuit controlling member 7. In the arrangement shown, the armature 10 is carried directly on the left-hand end of the circuit controlling member 7, and the attractive effort between the magnet 8 and its armature 10 tends to turn the circuit controlling member clockwise and to hold it against counterclockwise movement. In order to prevent sticking of the armature 10 to the poles of the magnet 8, suitable air gap or spacing means, such as a thin magnetic shim, not shown, may be employed, as is well known to the art; but for the highest ratio of dropout to pickup and the lowest possible potential burden, the gap should be the smallest possible.

In accordance with my invention, the electromagnetic unit 6 is of the induction motor type in order to provide on the circuit controlling member 7 a steady torque which is independent of cyclic variation in the alternating current quantity by which the unit is energized. As schematically illustrated, the unit 6 is an induction cylinder device of the type disclosed in United States Letters Patent Re. 21,813, dated May 27, 1941, and assigned to the assignee of this invention. The illustrated unit 6 comprises an outer stationary hollow magnetic stator 11 having a plurality of inwardly projecting poles 12 and 13, a series of interconnected energizing windings 14, one on each of these poles, a series of interconnected flux phase displacing windings 15, one on each of the poles 13, a central stationary magnetic stator 16, a non-magnetic metallic cylinder 17 mounted on a shaft 18 to rotate in the gaps between the poles 12, 13 and the inner stator 16, and the circuit controlling member 7 which may be mounted directly on the shaft 18, as shown. A light blasing or return means, such as a spring 19, may be provided to tend to turn the circuit controlling member 7 clockwise, especially when the unit 6 is deenergized. Also as illustrated, the circuit controlling member 7 is provided with circuit opening contacts 20 and circuit closing contacts 21.

Since the induction motor element or unit 6 is inherently incapable of producing any torque

in consequence of energization by a continuous current, offset currents do not interfere with its correct operation. In order to prevent false operation on transient currents such as frequently occur at the inception of a fault, I provide for the phase displacing windings 15 a circuit whose resistance and inductive and capacitive reactances are so proportioned as to constitute a substantially critically damped predetermined power factor circuit at the frequency of the energizing circuit, all as disclosed, for example, in United States Letters Patent 2,131,608, dated September 27, 1938. As illustrated, this circuit comprises a capacitance 22 and a resistance 23 in parallel therewith and both in series with the series connected phase displacing windings 15. Prevention of false operation on transient currents is thus effected by the losses in this critically damped or dead-beat circuit and is also further enhanced by choosing the power factor of this circuit such as to provide a phase displacement of the fluxes in the poles 13 relatively to the fluxes in the poles 10 to produce maximum torque only at system frequency.

For so-called distance response to the impedance of the circuit 2, 3, 4 between the relay location and a fault point, the electromagnetic units 5 and 6 are respectively energized in accordance with a voltage and a current of the circuit. In order to have like reach or sensitivity of response to interphase faults involving either two or three of the phase conductors 2, 3 and 4, the current energization for a relay responsive to a phase fault involving conductors 2 and 3 is preferably in accordance with the vector difference between the currents flowing in these conductors. This vector difference current may be derived from the circuit conductors 2 and 3 by two differentially connected current transformers 24 and 25 in series relation with these conductors and having in their secondary circuit the series connected windings 14 of the electromagnetic unit 6. The torque on the rotor 17 of this unit is therefore substantially directly proportional to I^2 or equal to $K_1 I^2$ since the angular displacement of the fluxes in the poles 13 relatively to the fluxes in the poles 12 is fixed. In this expression $K_1 I^2$, I is the vector difference of the currents in the phase conductors 2 and 3, and K_1 is a constant embodying factors in construction and design. Moreover, since the electromagnetic unit 6 is of the induction motor type, its torque is independent of cyclic variation of the current I and also is not affected by offset current waves. Also, because of the critically damped and predetermined power factor circuit of the flux displacing windings 15, the unit 6 is substantially unaffected by transient currents.

The voltage responsive unit 5 is energized through the medium of a potential transformer 26 which is connected to be energized in accordance with the voltage E between the phase conductors 2 and 3. Now, if the unit 5 acted on its armature 10 with an effect directly proportional to E^2 , the movement of the circuit controlling member 7 at the balance point would be in accordance with the predetermined value $(Z')^2$ at which operation is desired since at the balance point the equation of the torques gives

$$\left(\frac{E}{I}\right)^2$$

However, I have found that because of magnetic leakage, saturation, and possibly other factors, the effect of the unit 5 is not directly proportional

to E^2 but to some variable power of E between the first and second so that the actuation of the circuit controlling member for different magnitudes of E and I would not always be the desired predetermined setting Z' but would vary from Z' depending on the magnitudes of E and I . While this is not so material when a distance relay is used merely as a fault detector, it does become quite critical when it is desired to use the relay as a true ohmic responsive or precision distance measuring device. In order to obtain such close measuring or ohmic response, I provide, in accordance with my invention, means for so matching the response characteristic of the unit 5 to the response characteristic of the unit 6 that at the balance point their response is a true Z' response based on the comparison of torques respectively substantially proportional to E^2 and I^2 . For this purpose, I use a non-linear impedance means which modifies and compensates or corrects the characteristic of the voltage unit 5 so that its response is substantially $K_1 E^2$. Then, at the balance or operating point, it is immaterial what the magnitudes of E and I are since the relay will always respond to the ratio

$$\left(\frac{E}{I}\right)^2$$

or $(Z')^2$ whenever the ratio of E to I is less than Z' or, in other words, whenever the fault is within a predetermined distance of the relay.

As a suitable non-linear impedance means capable of providing satisfactory operation, I may use a full wave copper oxide rectifier 27 connected to be energized from the potential transformer 26 and to supply the energizing winding 9 of the voltage unit, as shown. I believe that the satisfactory modification of the characteristic of the voltage unit 5 which results from the use of the copper oxide rectifier 27 is due to the fact that at low currents the copper oxide rectifier is relatively inefficient, but at high currents its efficiency improves, and, in consequence of this action, the characteristic of the voltage unit 5, which may at low voltage closely approximate $K_1 E^2$ and then fall off to a different value of about $K_1 E^{1.5}$, is brought back to substantially $K_1 E^2$ by the more efficient action of the rectifier at higher currents. Whatever the theory of the action is, I have found that without the use of the rectifier, that is, with the winding 9 directly connected to the potential transformer 26, the safe practical reach of a relay constructed in accordance with my invention is only about 75% of the distance from one relaying point to the next relaying point or, differently stated, 75% of the line section under protection by the relay whereas with the use of the non-linear impedance means, further in accordance with my invention, the practical reach for reliable operation is as high as 95% of the line section.

While other non-linear impedance means, such as silicon carbide resistance material of the type disclosed in United States Letters Patent 1,822,742, dated September 8, 1931, or even a saturating reactor in series with the potential magnet winding 9 may be used, the use of the copper oxide rectifier has the additional advantages of providing a steadier torque with lower potential burden since the rectifier causes the current in the potential winding 9 to be unidirectional and the inductance of the winding tends to level the current. Also the rectifier is somewhat smaller and more economical than the

aforementioned silicon carbide resistance material. Thus, with the substantially continuous current output of the rectifier 27, the torque effect of the voltage unit is substantially independent of cyclic variation in the voltage. Furthermore, the movable magnetic armature electromagnetic device 5 because of its inherently low potential burden characteristic, which is less than that of an induction motor unit such as the unit 6, does not so load the potential transformer as to destroy the linearity of its output and thereby affect the accuracy of either measuring devices or the relay itself.

In order to adjust the pickup impedance value Z' at which the relay 1 operates to close its contacts 21, the winding 9 of the voltage energized electromagnetic unit 5 may be provided with taps or a suitably tapped intermediate autotransformer 28 may be employed. Such means provide a relatively simple way of changing the voltage restraint and thereby the impedance value to which the relay responds.

Assuming the circuit controlling member 7 in the position shown in the drawing and that a fault occurs on the circuit 2, 3, 4, then if the impedance of the circuit between the relay and the fault is less than the impedance value Z' for which the relay 1 is set to respond, the current unit 6 will overcome the restraint of the voltage unit 5 to turn the circuit controlling member 7 counterclockwise and thereby cause engagement of the contacts 21. However, for any fault beyond the impedance range or pickup value Z' of the relay 1, the restraint of the voltage unit 5 predominates over the operating effect or torque of the current unit 6 to maintain the circuit controlling member 7 in the position shown. I have found that with the use of the rectifier 27 the impedance response characteristic of the relay 1 is substantially a circle and independent of the phase angle displacement between the voltage and the current energizing the relay. As will be obvious to those skilled in the art, three of these relays are preferably installed at any point in a three-phase system in order to take care of each individual phase for faults involving only that phase.

While I have shown and described my invention in considerable detail, I do not desire to be limited to the exact arrangement shown, but seek to cover in the appended claims all those modifications that fall within the true spirit and scope of my invention.

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

1. A high speed electroresponsive device operative in dependence on a predetermined relation between the effective values of two alternating current electric quantities comprising a movable member and means for exerting on said member two opposing effects respectively dependent on said alternating current quantities including a first electromagnetic unit adapted when energized by one of said quantities to exert on said member an effect which is independent of cyclic variation of said one quantity, of any phase displacement between the two quantities and of any offset in the wave of said one quantity, means for rendering the operation of said first electromagnetic unit independent of transients in the wave of said one quantity, and a second low volt-ampere burden electromagnetic unit adapted when energized by the other of said quantities to exert on said member an effect op-

posing the effect of said first electromagnetic unit, the resultant effect of said two units being such as to cause movement of said member in one direction when the effect of the first electromagnetic unit exceeds the effect of the second electromagnetic unit and to move said member in the opposite direction and hold it in a predetermined position when the effect of the second electromagnetic unit exceeds the effect of the first electromagnetic unit.

2. A high speed distance responsive relay operative in dependence on a predetermined relation between the effective values of a voltage and a current of an alternating current circuit comprising a movable circuit controlling member and means for exerting on said member two opposing effects respectively dependent on said voltage and said current including an induction motor unit adapted when energized by said current to exert on said member an effect which is independent of cyclic variation of the current, of any phase displacement between the voltage and the current and of any offset in the wave of the current, means for rendering the operation of said induction motor unit independent of transients in said current, and a low volt-ampere burden electromagnetic movable magnetic armature unit adapted when energized by said voltage to exert on said member an effect opposing the effect of said induction motor unit, the resultant effect of said two units being such as to cause movement of said member in one direction when the effect of the induction motor unit exceeds the effect of the movable magnetic armature unit and to move said member in the opposite direction and maintain it in a predetermined position when the effect of the movable magnetic armature unit exceeds the effect of the induction motor unit.

3. An electroresponsive device operative in dependence on a predetermined relation between the effective values of two alternating current electric quantities comprising a movable member, and means for exerting on said member two opposing effects respectively dependent on said alternating current quantities comprising two co-operating electromagnetic means having different operating characteristics and respectively connected to be energized in accordance with said alternating current quantities, and means for so modifying the operating characteristic of one of said electromagnetic means with respect to the operating characteristic of the other electromagnetic means as to maintain the response of said device at said predetermined relation regardless of the magnitudes of the effective values of said two alternating current quantities.

4. An electroresponsive device operative in dependence on a predetermined value of the ratio of the effective values of two alternating current quantities comprising a movable member, and means for exerting on said member two opposing effects respectively dependent on said alternating current quantities comprising two co-operating electromagnetic means having different operating characteristics and respectively connected to be energized in accordance with said alternating current quantities, and non-linear impedance means in circuit with one of said electromagnetic means for so modifying the operating characteristic thereof with respect to the operating characteristic of the other electromagnetic means as to maintain the response of said device at said predetermined ratio value regardless of the magnitudes of the effective values of said two alternating current quantities.

5. A relay device responsive to an ohmic quantity of an alternating current circuit comprising a movable circuit controlling member, and means for exerting on said member two opposing effects respectively dependent on a current and a voltage of the circuit comprising a first electromagnetic means of a predetermined type operative in accordance with a predetermined function of the current of the circuit and substantially independent of cyclic variation of such current, opposing electromagnetic means of a different predetermined type inherently operative in accordance with a function of a voltage of the circuit differing from the current function of said first electromagnetic means, and means for so matching the voltage function of said opposing electromagnetic means to the current function of said first electromagnetic means that the ohmic response of the relay is substantially constant regardless of the magnitudes of the effective values of the circuit current and voltage.

6. An electroresponsive device operative in dependence on a predetermined value of the ratio of the current to the voltage of an electric circuit comprising a movable circuit controlling member, and means for exerting on said member two opposing effects respectively dependent on said current and voltage comprising two cooperating electromagnetic means having different operating characteristics and respectively connected to be energized in accordance with said current and voltage, and non-linear impedance means in circuit with the winding of one of said electromagnetic means for so modifying the inherent operating characteristic thereof relatively to the operating characteristic of the other electromagnetic means as to maintain the pickup response of said circuit controlling member at said predetermined ratio regardless of the magnitudes of the effective values of the current and voltage.

7. An electroresponsive device operative in dependence on a predetermined relation between the effective values of two alternating current quantities comprising a rotatably mounted member, means for turning said member in one direction comprising an induction motor connected to be energized by one of said quantities and operative to exert on said member a torque substantially proportional to the second power of said one of said quantities and substantially independent of the cyclic variation thereof, and means tending to hold said member against turning by said motor comprising a magnetic armature mounted to partake of the movement of said member, electromagnetic means for attracting said armature inherently operative when directly energized by the other of said quantities to exert on the armature an attractive force substantially directly proportional to some power of said other quan-

tity between the first and second power, and non-linear impedance means in circuit with the winding of said electromagnetic means for so modifying the inherent operation of the electromagnetic means as to cause said means to function substantially in accordance with the square of the other quantity whereby to maintain the response of the device substantially constant regardless of the magnitudes of the effective values of the two quantities.

8. An impedance relay operative in dependence on a predetermined value of the ratio of a voltage of an alternating current circuit to a current of the circuit comprising a movable circuit controlling member and means for controlling the movement of said member in accordance with two opposing effects respectively dependent on said circuit current and voltage comprising an induction motor device connected to be energized in accordance with said circuit current and arranged to exert on said member a torque substantially proportional to the second power of the effective value of said circuit current and substantially independent of the cyclic variation thereof, a cooperating movable magnetic armature device connected to be energized in accordance with said circuit voltage and inherently operative in accordance with some power of the voltage between the first and the second power, and non-linear impedance means for so modifying the inherent operation of said cooperating magnetic device that it functions substantially in accordance with the square of the voltage whereby to maintain the ohmic response of the relay substantially constant regardless of the magnitudes of the effective values of the circuit current and voltage.

9. A relay device responsive to an ohmic quantity of an alternating current circuit comprising a movable circuit controlling member, and means for exerting on said member two opposing effects respectively dependent on a current and a voltage of the circuit, comprising a first electromagnetic means of a predetermined type operative in accordance with a predetermined function of the current of the circuit and substantially independent of cyclic variation of such current, opposing electromagnetic means of a different predetermined type inherently operative in accordance with a function of a voltage of the circuit differing from the current function of said first electromagnetic means, and means for so matching the voltage function of said opposing electromagnetic means to the current function of said first electromagnetic means that the ohmic response of the relay is substantially constant regardless of the relative effective values of the circuit current and voltage.

ALBERT R. VAN C. WARRINGTON.

CERTIFICATE OF CORRECTION.

Patent No. 2,352,985.

July 4, 1944.

ALBERT R. van C. WARRINGTON.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 1, second column, line 29, for "Fⁿ" read --Iⁿ--; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 22nd day of August, A. D. 1944.

Leslie Frazer

Acting Commissioner of Patents.

(Seal)