L. T. ROBINSON & J. R. CRAIGHEAD.

TRANSFORMER.

APPLICATION FILED JAN. 3, 1913.

1,129,231. Patented Feb. 23, 1915.

Fig. 1.

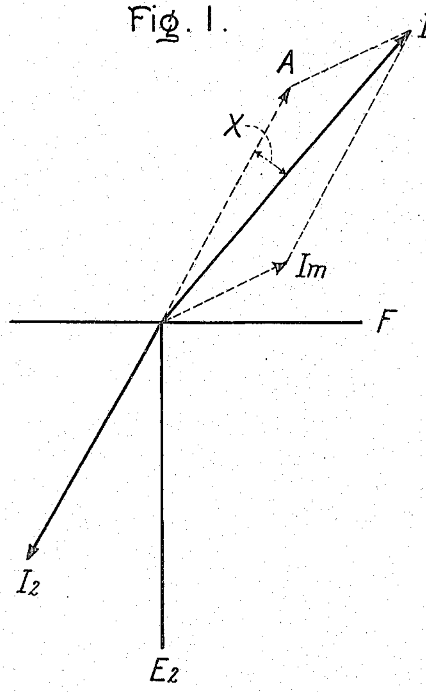


Fig. 2.

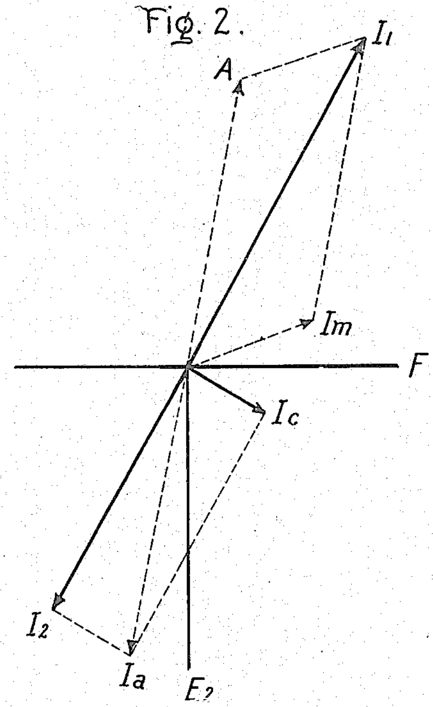
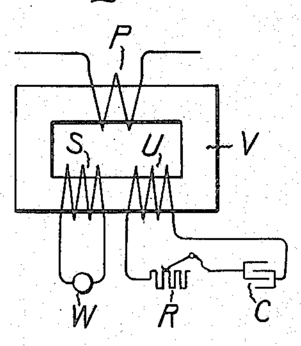


Fig. 3.



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UNITED STATES PATENT OFFICE.

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TRANSFORMER.

1,129,231. Specification of Letters Patent. Patented Feb. 23, 1915.

Application filed January 3, 1913. Serial No. 739,981.

To all whom it may concern:

Be it known that we, LEWIS T. ROBINSON and JAMES R. CRAIGHEAD, citizens of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Transformers, of which the following is a specification.

Our invention relates particularly to current transformers for power measurement, the object being to provide a transformer in which the phase angle between the primary current and the current delivered by the transformer is controlled in a manner most favorable for the purpose of accurate power measurement. Our invention, however, is not limited in its application to current transformers but is generally applicable to all transformers where a reduction in the phase angle or its elimination is desirable, but since the current or series transformer is one of the most common pieces of apparatus to which our invention is applicable, and in connection with which it may be readily understood, we shall describe our invention as applied to such a transformer.

The current transformer which is ordinarily used for power measurement consists of a core of iron on which is wound a coil of insulated wire to be connected in series with the supply circuit, and another coil of insulated wire to which the instrument or instruments are to be connected. Due to various causes, the current delivered to the instruments is not in exact phase opposition to the current in the primary of the transformer, and thereby error is introduced, the secondary current not accurately representing the primary current. We propose to minimize this error.

In accordance with our invention we provide the transformer with a third or auxiliary circuit having its constants so chosen with reference to the constants of the instrument circuit that at any predetermined load the instrument current may be made to be substantially in phase opposition to the primary current.

In the preferred form of our invention the third or auxiliary circuit comprises a separate secondary winding on the core of the transformer and a suitable load, resistance, inductance, capacity or combination of any of these as may be required, connected to the terminals thereof. In such an apparatus the total secondary current in effect consists of the summation of the current in the instrument circuit (or main secondary circuit) and the current in the auxiliary circuit. Thus the product of the current in the main secondary winding by the number of turns in this winding (ampere turns) combined, with due regard to phase relation, with the product of the current in the auxiliary winding by its number of turns (ampere turns), constitutes the total secondary ampere turns and is substantially equal to the product of the primary current by its number of turns (primary ampere turns). By providing the auxiliary circuit with suitable constants the current in that winding may be made to be in phase with the induced voltage or may be made to lag behind or to lead the induced voltage by any desired angle. Thus the main secondary current, usually somewhat lagging with respect to the induced voltage, may be made to lag or lead the total secondary current as may be necessary, and thus may be brought into phase opposition to the primary current. The loading of the auxiliary circuit should preferably be such that the current in the auxiliary circuit is as nearly as possible in quadrature with that in the instrument circuit, since then the change of phase angle with a given change of primary current is a minimum. If the normal phase angle is positive, that is, if the secondary current is leading with respect to the normal primary current, capacity or resistance, or a combination of the two is suitable, while in the case of the secondary current lagging with respect to the primary current, inductance in the auxiliary circuit is preferable. Resistance and inductance combined is not ordinarily desirable since for the correction desired these two act in a measure to oppose each other.

The amount and kind of load required on the extra winding is not a simple function of the exciting current of the transformer but depends also on the amount and kind of load on the primary and main secondary circuits. The phase angle of a current transformer usually varies with the value of the current flowing in its primary and with the nature of the secondary load, and therefore it will not usually be possible to make any single adjustment which will keep the phase angle at zero for the entire range of primary current and for different instrument loads. It is possible, however, to make such an adjustment with a particular instrument load that the phase angle becomes zero at any desired value of primary current. Thus, if this value is the average or normal value of the primary current, the average value of the phase angle is zero and the maximum value is greatly decreased. By making separate adjustments for each secondary load and each primary current value, the phase angle may be brought practically to zero for every condition. By so designing the auxiliary circuit that the current therein is approximately in quadrature to the instrument current a minimum change in phase angle occurs with a change in load current without change of adjustment.

Our invention may be further explained by means of the accompanying drawings.

Figure 1 is a vector diagram of a series transformer; Fig. 2 is a vector diagram of a series transformer provided with a third or auxiliary circuit arranged in accordance with our invention; Fig. 3 illustrates the preferred embodiment of our invention, in which the third circuit comprises a separate secondary winding.

The vector diagram of an ordinary series transformer may be constructed as illustrated in Fig. 1. I_2 is the current in the secondary circuit represented in phase and value (the latter in ampere turns). F is the phase of the flux in the transformer core. E_2 is the electromotive force induced in the secondary circuit (value disregarded). The load on the secondary circuit has been assumed to be an inductive one, since this is the usual condition met with in practice. An exciting current I_m is required to produce the flux in the core. The total primary current required is the summation of the exciting current I_m and the secondary current reversed A; adding these vectorally we find the primary current (in ampere turns) to be I_1 in phase and value. It is apparent from these considerations that there is under all conditions a certain angle between the secondary current reversed A and the primary current I_1 unless the secondary current is in phase with the exciting current I_m, since there must always be an exciting current of appreciable value. The secondary current in exact phase opposition to the exciting current is an unusual condition. The angle between the two currents is called the phase angle of the transformer and for the conditions already given is represented by the angle X. This is never zero for any finite value of currents. By our invention we propose to reduce the maximum value of the phase angle, and to make this phase angle zero at some particular load and value of primary current. As has already been set forth, we prefer to do this by providing a third or auxiliary circuit having the proper constants.

In Fig. 2 we have shown a vector diagram of a transformer constructed in accordance with our invention, wherein the third auxiliary circuit includes both resistance and capacity. The flux is represented by F as in the preceding diagram; the main secondary current I_2, which is the instrument current and which is lagging with respect to its electromotive force E_2, since this is the most common condition, and the exciting current I_m, are both again represented in ampere turns. I_c represents in ampere turns the current in the auxiliary secondary circuit, approximately in quadrature to the instrument current by preference, this current being determined in phase and value by the amount of resistance and capacity in the auxiliary circuit and the number of turns on the common core. Combining I_2 and I_c, the resultant or total secondary current is found to be I_a. I_a reversed as shown by A_1 and combined with the exciting current I_m shows the current I_1 in the primary. It will be seen from the diagram that for the values of ampere turns and the phases assumed, I_1, the primary current, is exactly in phase opposition with the secondary current I_2, or in other words, that the instrument current vector I_2 reversed would lie along the primary current vector I_1, the phase angle of the transformer being zero.

Although now the phase angle may change with an increase or decrease of primary current, the constants of the auxiliary circuit remaining the same, it must change from zero in each case, and by causing the auxiliary current to be in quadrature to the instrument current a minimum change is experienced. We have provided therefore a transformer with a smaller maximum phase angle and one in which the phase angle can be made zero for any desired value of primary current and in which the change of phase angle is a minimum with a given change in value of primary current.

Fig. 3 illustrates diagrammatically a series transformer constructed in accordance with our invention wherein the auxiliary secondary circuit U contains both resistance R and capacity C, the resistance member R, however, only being used where resistance in addition to that offered by the windings and connections is required. The main secondary S is located on the single core V and supplies an instrument winding as, for example, a winding of a wattmeter W. The primary P is connected in series with the line, as will be understood. The values of the resistance R and capacity C are preferably adjusted so that the current in their circuit is substantially in quadrature with the current in the instrument circuit and of such value that the instrument current is approximately in phase with the primary current at the normal or average value of the primary current with the given instrument load W.

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

1. A transformer including a primary winding, a secondary winding and a closed auxiliary winding, the constants of the auxiliary winding circuit being such that with a load of definite constants on the secondary winding the currents in the secondary winding and auxiliary winding are approximately in quadrature.

2. A transformer including a primary winding, a secondary winding and a closed auxiliary winding, the constants of the auxiliary winding circuit being such that with a load of definite constants on the secondary winding the currents in the secondary winding and auxiliary winding are approximately in quadrature, and that with a certain value of current in the primary winding, that current and the main secondary current are in phase opposition.

3. The combination with a transformer comprising a primary winding, a secondary winding and an auxiliary winding, of an instrument connected to the secondary winding, a resistance member and a capacity member connected to the auxiliary winding, the constants of the auxiliary winding circuit being such that currents induced in the secondary circuit and auxiliary circuit are approximately in quadrature.

4. The combination with a transformer comprising a primary winding, a secondary winding and an auxiliary winding, of an instrument connected to the secondary winding, and a capacity member connected to the auxiliary winding, the constants of the auxiliary winding circuit being such that currents induced in the secondary circuit and auxiliary circuit are approximately in quadrature.

5. The method of reducing the phase angle in a transformer which consists in adding to the effect of the instrument current on the primary circuit another secondary current effect in quadrature to the instrument current effect.

6. The method of reducing the phase angle in a transformer which consists in adding to the effect of the instrument current on the primary circuit another secondary current effect in quadrature to the instrument current effect, the summation of the secondary currents effects with a load of certain constants on the secondary winding and at a certain value of primary current being such that the instrument current is in phase opposition to the primary current.

7. In combination with an instrument transformer comprising a primary winding, a secondary winding, and an auxiliary winding, of an instrument connected to the secondary winding, a resistance member and a capacity member connected to the auxiliary winding, the constants of the auxiliary winding circuit being such that with a load of definite constants connected to the secondary winding and at a predetermined value of current in the primary winding, the current in the main secondary winding is in phase opposition to the current in the primary winding.

In witness whereof, we have hereunto set our hands this 31st day of December, 1912.

LEWIS T. ROBINSON.
JAMES R. CRAIGHEAD.

Witnesses:
MARGARET E. WOOLLEY,
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