July 5, 1932. R. H. BORKENT 1,865,430

CURRENT TRANSFORMER

Filed June 18, 1930

Fig. 1.

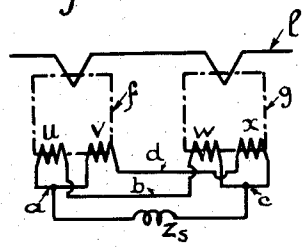


Fig. 2.

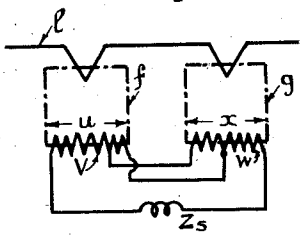


Fig. 3.

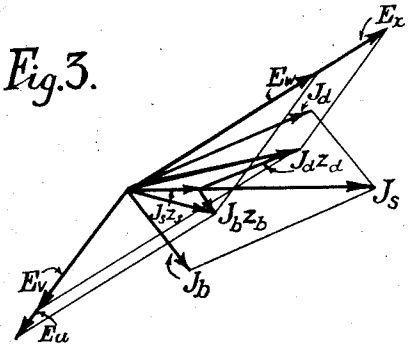


Fig. 4.

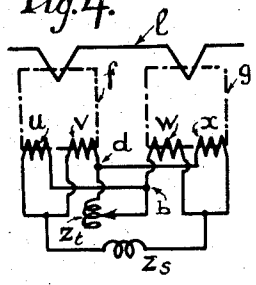


Fig. 5.

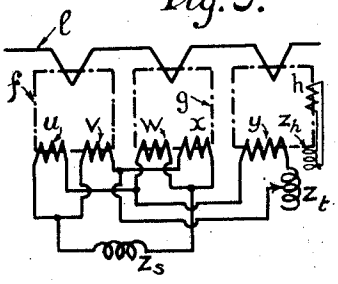


Fig. 6.

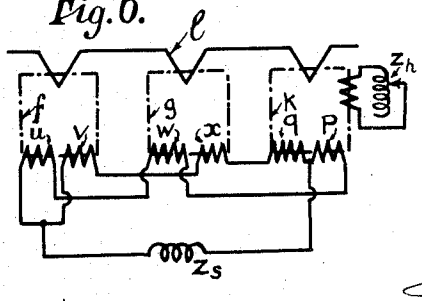
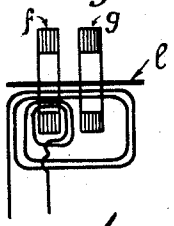


Fig. 7.



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UNITED STATES PATENT OFFICE

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CURRENT TRANSFORMER

Application filed June 18, 1930, Serial No. 461,978, and in the Netherlands June 25, 1929.

The invention relates to a current transformer the secondary current of which can be made proportional to the primary current with a very high degree of accuracy. The invention is especially adaptable to "straight-through" bushing transformers.

With ordinary types of current transformers the magnetic induction in the cores is very small, therefore the magnetizing current and the errors of the transformer are large. The errors can be decreased by choosing the working range of the transformer nearer to the point of maximum permeability, the application of this effect being called pre-magnetization. The invention gives a solution of the problem to decrease the error of current transformers by increasing and by adjusting the magnetic induction in the core material. The general object of the invention is to provide parallel branches in the secondary winding of the current transformer, giving rise to internal currents flowing in the secondary winding. With types known in the art said increase of the magnetic induction (pre-magnetization) is obtained by giving the transformer an auxiliary winding connected to an auxiliary potential. Said auxiliary winding is so arranged that there is neither mutual inductance between said winding and the secondary nor between the same and the primary windings of the transformer. The current in said auxiliary winding therefore does not alter the currents in the other windings of the transformer, apart from the indirect influence caused by the increase of the magnetic induction, which influence is exactly the purpose of the auxiliary winding. On the contrary with types according to the invention, various parts of the secondary windings are coupled magnetically and a number of said couplings have a direct influence on the current intensities in the different parts of the secondary windings, that is as a consequence of the mutual inductance between some secondary coils, electromotive forces are induced in them, which electromotive forces influence the currents in the secondary windings. Said internal secondary currents together with the primary current produce the ampere turns, necessary to obtain the suitable value of the magnetic induction in the various parts of the core material.

According to the invention the secondary winding possesses a number of coils, which are connected electrically as well as coupled magnetically in such a manner that a number (that is more than one) of said magnetic couplings have a direct influence on the current intensities in the different parts of the secondary winding.

In this specification the total of succeeding turns embracing the same magnetic flux and flown through by the same current, is called a coil. As a limit case such a coil may consist of one single turn.

According to a characteristic of the invention, the suitable values of the internal current intensities in the different parts of the secondary windings are adjusted by giving the secondary windings parallel branches in such a manner that in more than one of the branches two or more coils, differing in their number of turns, and placed on more than one or on separate cores, are connected in series.

An impedance may be connected in parallel to a coil; or one or more bridge branches, wherein an electromotive force is induced, may be inserted.

The proper values of said currents may also be obtained or adjusted by two or more secondary circuits, which are separated electrically. In constructional forms embodying the invention the distribution of said currents may still be varied by modifying the constants of the magnetic circuits. This may be brought into practice, for instance by providing magnetic shunts or air gaps in the magnetic circuits, or by the choice of special sections and special core material of the different cores.

The invention will be better understood from the following description taken in connection with the accompanying drawing, in which Fig. 1 is a diagrammatic view of a current transformer according to the invention, and shows an application which gives favourable results in a simple manner. Fig. 2 shows an arrangement almost similar to

that of Fig. 1 whereby some secondary coils are partially combined; Fig. 3 is a vectorial representation of the current and voltage relations obtaining in a transformer of the character described in connection with Fig. 1. In Fig. 4 a bridge branch is added to the arrangement of Fig. 1, wherein an impedance is inserted. In Fig. 5 in said bridge branch also an electromotive force is inserted. Fig. 6 shows an extended arrangement of Fig. 1 with three cores. Fig. 7 shows diagrammatically how the cores may be partially combined.

Like reference characters refer to similar parts in the different figures of the drawing.

In Fig. 1 the primary conductor is marked l; the cores on which the four coils u, v, w and x are placed, are indicated by f and g. The numbers of the turns of these coils are indicated by the same reference characters. Choosing the number of the turns accordingly, it is possible to obtain in both cores magnetizing fields of suitable value, inducing electromotive forces in said coils. The effective values of said electromotive forces are respectively called E_u, E_v, E_w and E_x. The current in the branch a, u, b, w, c is called I_b; the current in the branch a, v, d, x, c is called I_d and the current through the instrument, for instance a measuring instrument, I_s. The impedance of said three branches are called respectively z_b, z_d (consisting of ohmic-resistance and leakage-reactances) and z_s. Further I_p and I_s are in size and phase the intensities of the primary and secondary current, these currents having a phase difference of approximately 180°; W_p is the number of the turns of the primary winding; L is the mean length of the lines of magnetic induction (in the case of the cores having such a shape that the magnetic circuits contain parallel branches, for instance in the case of cores of the shell-type, L may refer to the mean length of the lines of magnetic induction of the respective branch); and the real number r is the ratio of the current transformer, that is the ratio of the nominal values of the primary and the secondary current.

Departing from ordinary types of current transformers where the magnetizing ampere turns are equal to the vectorial sum of the ampere turns of the primary and the secondary current, that is equal to

$$\frac{W_p}{L}(I_p \hat{+} rI_s)$$

ampere turns per centimeter (the deviation from this value, caused, for instance, by a compensation of the number of the secondary turns, or by a circuit shunting the secondary load, as is sometimes done in order to correct the ratio and the phase angle of the current transformer, is of no interest here, as said complications have no influence on the order of the magnitude of the magnetomotive force) the magnetizing ampere turns of core f are equal to $I_p W_p \hat{+} I_b u \hat{+} I_d v$ and those of core g are equal to $I_p W_p \hat{+} I_b w \hat{+} I_d x$. Said ampere turns cause in the cores the magnetic fields which induce in the secondary windings the electromotive forces E_u, E_v, E_w and E_x, whereby

$$\frac{E_w}{E_x} = \frac{w}{x} \text{ and } \frac{E_v}{E_u} = \frac{v}{u}.$$

Refering now to the vectorial representation of the voltage relations of Fig. 3 the sum $E_w \hat{+} E_u$ as well as the sum $E_v \hat{+} E_x$ must be equal to the sum of the voltage between the secondary terminals of the transformer $I_s z_s$ and the potential drop $I_b z_b$ respectively $I_d z_d$ in the branch.

By way of a specific example let the cross sectional areas of the cores be equal, let z_s= 0,6 ohm, $z_b = z_d$=L, 2 ohm, I_p=60 amp., I_s= 0,5 amp., W_p=1, u=150, w=90, $v = x$=119, then the calculation of the currents and voltages according to the principles given above will show:

E_u=0,68 volt; I_b=0,15 amp.; $\frac{1}{2} I_s z_s$=0,15 volt;
E_v=0,55 volt; I_d=0,41 amp.;
E_w=0,90 volt; arc (I_d—I_d)=69 degrees;
E_x=1,20 volt;
arc (E_u—E_x)=154 degrees.

The proportion of the magnetic inductions in the cores f and g being

$$\frac{E_v}{E_x} = \frac{0,55}{1,20} = 0,458$$

(according to the fact that the cross sections of the cores are equal and the number of turns of the coils v and x are the same) this example shows clearly the unequal magnetization of the cores, thus departing from the already mentioned types known in the art, where the magnetic inductions in the cores are imperatively the same. An unequal—undesired—magnetization of the cores deteriorates the accuracy of the pre-magnetized current transformers known in the art. According to the invention the unequal magnetization is always taken into account when designing the current transformer.

It is evident that in a general way the cross sections of the cores need not be equal, the leakage reactances of the brances b and d need not be zero and the number of the turns of the coils v and x need not be the same, as they are in the specific example for the sake of simplicity. Further from said example should not be concluded that the unequal magnetization of the cores is an imperative property of the embodiments of the invention; it is a matter of course that in special cases the inductions in the cores may be equal.

The invention offers a great number of degrees of freedom to the designer to compensate the errors almost entirely; the invention enables the construction of accurate current transformers of a simple type. Said

number of degrees of freedom, already suggested by the preceding example, (for instance the choice of the ratio of the number of the turns, and the ratio of the impedances of the coils and the modifications which may be carried out in an easy manner) may for instance be enlarged as shown in the other figures of the drawing.

In Fig. 2 the coils u and v, as well as w and x are combined, offering an opportunity for saving coil material.

In Fig. 4 a bridge branch containing an adjustable impedance z_t, is placed between the points b and d.

In Fig. 5 moreover an electromotive force is inserted in said bridge branch, which electromotive force is obtained by induction with the aid of a third core. Said electromotive force may be regulated in size and phase, for instance by an additional winding h closed upon an adjustable impedance z_h, whilst said circuit may also contain an electromotive force. The part of the secondary winding, which is connected electrically to the secondary burden z_s, is a kind of Wheatstone bridge, the coils u, v, w and x composing the sides of the quadrangle, and z_s and the branch z_t being the diagonals. This permits the current I_s flowing through z_s to be approximately independent from z_t and inversely, as should be the case with a current transformer (the secondary current I_s should always be proportional to the primary current I_p).

The suitable values of the currents I_b and I_d may also be obtained by using three or more cores.

Fig. 6 gives a combination with three cores in order to influence the division of the current I_s into I_b and I_d.

The coils as well as the cores may be partially combined.

Fig. 7 shows diagrammatically how the cores may be combined, offering an opportunity to save core material. For the sake of clearness only the windings u and w are shown. Here a number of w turns embrace both cores f and g, and a number of u-w turns embrace only the core f.

It is to be understood that such changes may be made in the arrangement, number and connection of the several parts as shall fall within the scope of the appended claims.

I claim:

1. A current transformer, comprising a plurality of magnetic cores some of them bearing each a plurality of electrically connected secondary coils, the several coils of at least two cores being such, that the number of turns of the coils upon the same core differ from each other, the secondary winding of the transformer comprising parallel branches formed by coils upon a plurality of cores.

2. A current transformer as specified in claim 1, in which in several branches several coils differing in the number of turns and placed on separate cores are connected in series.

3. A current transformer as specified in claim 1, in which in several branches several coils differing in the number of turns and placed on separate cores are connected in series and including a bridge branch, in which electromotive forces may be induced.

4. A current transformer as specified in claim 1, in which in several branches several coils differing in the number of turns and placed on separate cores are connected in series and including a bridge branch, in which electromotive forces may be induced, and a regulating impedance added to the secondary winding.

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