

April 19, 1949.

G. CAMILLI ET AL

2,467,807

ELECTRIC INDUCTION APPARATUS

Filed Nov. 30, 1944

Fig. 1.

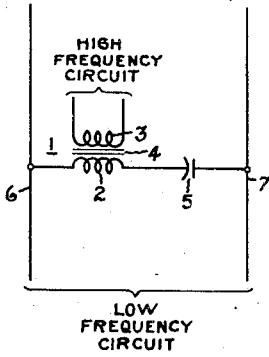


Fig. 2.

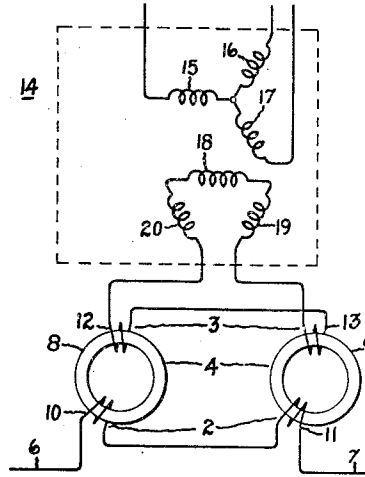


Fig. 4.

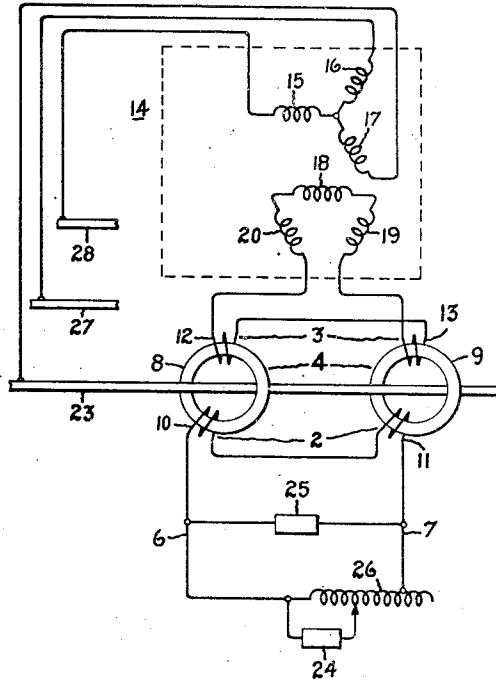
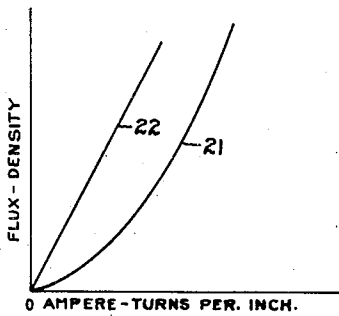


Fig. 3.



Inventors:
Guillermo Camilli,
Aram Boyajian,
by *Harry E. Dunham*
Their Attorney.

UNITED STATES PATENT OFFICE

2,467,807

ELECTRIC INDUCTION APPARATUS

Guglielmo Camilli and Aram Boyajian, Pittsfield, Mass., assignors to General Electric Company, a corporation of New York

Application November 30, 1944, Serial No. 565,832

13 Claims. (Cl. 323-89)

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Our invention relates to electric induction apparatus and more particularly to improvements in inductive devices having ferro-magnetic cores.

It is well known that a ferro-magnetic core increases the reactance of an inductor (inductive device) for alternating currents many fold over what it would be without the ferro-magnetic core, and thus renders the inductor highly economical, but it is also well known that such an inductor has non-linear volt-ampere characteristics. This non-linearity is objectionable in certain inductor applications, among which are resonant filter circuits and current transformers.

A general object of the invention is to linearize the normally non-linear characteristics of those inductive circuit elements which involve ferro-magnetic cores so that, where formerly such elements were unusable for lack of linear characteristics, they may become usable, and where they were of limited use, they may become more extensively usable.

Another object of the invention is to provide a new and improved electric inductive apparatus.

A further object of the invention is to provide a new and improved current transformer.

An additional object of the present invention is to improve the accuracy of the bushing type current transformer so as to greatly extend its possible field of commercial application in higher-voltage lower-current circuits.

A still further object of the invention in this connection is to secure the improved accuracy with auxiliary excitation of much lower frequency, such as triple frequency, so as to render the cost and convenience of the device commercially acceptable.

The invention will be better understood from the following description taken in connection with the accompanying drawing and its scope will be pointed out in the appended claims.

In the drawing, in which the same reference number designates the same element in the different diagrams, Fig. 1 illustrates diagrammatically a resonant circuit, such as may be used in a filter system, including an iron-cored inductor embodying schematically the present invention, Fig. 2 illustrates diagrammatically a preferred construction for such an inductor, Fig. 3 illustrates characteristic curves of such an inductor for a better understanding of the operation of such devices, and Fig. 4 illustrates diagrammatically an embodiment of the invention in a bushing-type current transformer.

Referring now to the drawing, and more particularly to Fig. 1, there is illustrated therein an

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inductor 1, with a main winding 2 and auxiliary winding 3, on a ferro-magnetic core 4. A capacitor 5 is connected in series with said main winding 2 between two terminals 6 and 7 of an alternating-current circuit. The elements 2 and 5 are so proportioned to each other that, at a predetermined frequency, the reactance of the inductor will be balanced or compensated for by the equal and opposite reactance of the capacitor, resulting in a substantially null reactive voltage between 6 and 7.

Heretofore, an inductor for such service has, in general, had to be either air-cored or provided with an air gap, because one with a ferro-magnetic core (especially one with a closed ferro-magnetic core) would have non-linear volt-ampere characteristics, and if the inductor were adjusted to be resonant with the capacitor at one value of current, it would not be so at another value of current.

We have discovered, however, that the normally non-linear volt-ampere characteristic curve of an inductor having a ferro-magnetic core can be linearized, even when the core is completely closed, if suitable auxiliary alternating magnetization of a higher frequency is superimposed on the normal-frequency magnetization of the core. When this is accomplished, the reactance of the inductor is rendered resonant with that of the capacitor over a wide range of current and voltage.

In the inductor construction for this purpose illustrated in Fig. 2, the ferro-magnetic core consists of two similar sub-cores 8 and 9, which may consist of cold-rolled silicon-steel strip wound up in ring form. The normal-frequency main winding 2 consists of the similar coils 10 and 11, in series, wound respectively on the sub-cores 8 and 9; and the auxiliary winding 3, for the higher-frequency magnetization of the core, consists of two similar coils 12 and 13, wound respectively on the sub-cores 8 and 9, and connected in series opposition with respect to the coils 10 and 11. It will be observed that the connections of 13 are reversed with respect to 12, considering their polarities with respect to the circuit of 10 and 11, so that the circuit of 12 and 13 is non-inductive with respect to the circuit of 10 and 11, and therefore neither circuit is capable of inducing a current in the other circuit, although each circuit is capable of magnetizing the sub-cores.

The necessary higher-frequency voltage, for the excitation of the auxiliary winding, is shown as furnished from a frequency-tripling source 14, comprising a bank of three single-phase trans-

formers with primary windings 15, 16 and 17, connected in Y and to be excited from a three-phase source (not shown), preferably a constant potential system which may be the same system to one phase of which the circuit of the coils 10 and 11 is connected. The secondary windings 18, 19 and 20 of the frequency-tripling transformers are connected in delta, with one corner of the delta open for connection into the circuit of coils 12 and 13, placing the elements 12, 13, 18, 19 and 20 all in series in a single-phase closed circuit, to cause triple-frequency currents to flow in this circuit when the aforementioned primary windings, connected in Y, are excited three-phase at normal frequency. The theory and design of such a frequency-tripling transformer is well known in the art and reference may be had for it to an engineering paper by J. L. Cantwell, entitled "Frequency Tripling Transformers," in the Transactions of the American Institute of Electrical Engineers, issue of July 1936, pp. 784-790.

The volt-ampere characteristic curve of this inductor with a closed magnetic circuit, of silicon-steel strip wound-up in ring form, is shown in Fig. 3. Curve 21 was obtained when no auxiliary excitation was used, and the curve 22 with auxiliary triple-frequency excitation superimposed on the normal-frequency excitation. The auxiliary excitation was impressed across the circuit of 12-13 and maintained constant at a frequency of 180 cycles per second and an intensity representing a 180-cycle flux density of approximately 25,000 lines per square inch in each core part, with 60-cycle excitation of varying intensities impressed across the circuit of 10 and 11, in the range of the curves shown. The abscissas of the curves are the 60-cycle current in ampere-turns per inch length of the magnetic circuits, and the ordinates the corresponding 60-cycle flux densities. The range of the curves is from zero to about .030 ampere-turn per inch and from zero to about 10,000 flux lines per square inch. For any given inductor the ampere-turns per inch are directly proportional to the amperes of exciting current and the flux density is directly proportional to the voltage of self induction in the exciting winding. Hence the designation of the curves as volt-ampere characteristics.

It will be observed that while 21 is distinctly non-linear, 22 is substantially a straight line, a major result sought for in the present invention.

It will be seen also that, for a given ordinate, the abscissa of 22 is considerably less than that of 21. Reduction of the exciting current is not desirable in a resonant system but some reduction may be unavoidable and is not particularly objectionable if not carried too far. The reason for this statement is as follows:

In a resonant system, the reactive components of the volt-amperes of both the inductor and the capacitor are essential to resonance, and the larger these components, the more pronounced is resonance. On the other hand, the watt components are antagonistic to resonance, and therefore the less these components the better. In general, resonance is proportional to the ratio of the wattless component to the watt component of the inductor volt-amperes. In the literature of the subject, this ratio is represented by Q . It follows from the foregoing that in modifying the volt-ampere characteristic curve of an inductor by means of an auxiliary excitation, a net gain in this resonance factor Q will be secured if the percentage reduction in the wattless component is

less than the percentage reduction in the watt component, and hence the lesser, the better. Therefore, the linearization of the characteristic curve of an inductor for a resonant circuit is preferably accomplished with no more change in the abscissas of the curve (that is, with no more reduction of the exciting current) than can be helped.

In this connection, it may be observed that, as the capacitor reactance must be adjusted to the linearized value of the inductor reactance, or vice versa, the fact that the magnitude of the linearized reactance is variable with the auxiliary excitation offers an opportunity for the tuning adjustment by varying the auxiliary excitation.

It may also be remarked in this connection that, while the watt losses in the auxiliary circuit do not enter as a factor in resonance, they still represent a waste of power, with the added problems of increased temperature rises and greater need for heat-dissipation means, etc.

In the choice of the frequency and magnitude of the auxiliary excitation to linearize the lower-frequency excitation curve, the foregoing principles should therefore be kept in view, and that combination of auxiliary frequency and auxiliary flux density should be preferred which effects the linearization with the greatest gain (or least loss) in these other considerations. In our studies with silicon-steel strip, at flux densities ranging from 1,000 to 10,000 lines per square inch—the range to be expected in many of the useful applications of the present invention—auxiliary excitation at triple-frequency was found to be more advantageous than a much higher one, such as a 7-fold frequency. This is very fortunate, because triple-frequency excitation is very conveniently and economically obtainable by the static means mentioned above, whereas higher-frequency supply equipments are expensive, inefficient, variable and difficult to maintain at optimum values, and have other disadvantages also. For this and other reasons, triple-frequency would be preferred for the auxiliary excitation even if it effected the linearization as well as but no better than still higher frequencies.

A lower frequency than the triple may also be used, but not the same frequency as that of the circuit to be linearized, for in the latter case the beneficial effect of the auxiliary excitation is both reduced and found to vary with the angular displacement between the two excitations, whereas with higher-frequency auxiliary excitation no important variation could be detected in our tests.

The flux density of this triple-frequency excitation to yield the best all-round results is one that has to be determined experimentally for each type of ferromagnetic alloy of which there are quite a number on the market now, some with various percentages of nickel or other metals, and having widely different magnetization characteristics. For a good grade of the silicon-steel strip now in extensive use, triple-frequency excitation at about 25,000 lines per square inch in the core was found to yield very good results when the normal frequency flux density is considerably below this. In the general case of a given ferro-magnetic alloy, the optimum auxiliary flux density has to be determined experimentally, but two guiding principles are as follows:

First, the auxiliary flux density is preferably considerably higher than the maximum flux density attained by the lower-frequency flux density in its normal operating range; and second, the resultant flux density is preferably in the general

zone of the highest permeability of the magnetic material. These two considerations may sometimes conflict, in which case a compromise has to be made, but in the case of the silicon-steel strip, operated at the lower densities, these two considerations practically agree at the figure given for the auxiliary flux density.

In the foregoing as well as in the following paragraphs, the terms "magnetization" and "excitation" and their derivatives are used generally synonymously. A core carrying a flux may be said to be either magnetized or excited. The winding producing the flux is generally said to be excited, and in its turn as exciting or magnetizing the core, but it is not conventional to refer to the winding as magnetized. The term "excitation" is, thus, convenient as applicable both to the magnetized core and the winding magnetizing it. The excitation of an alternating-current winding is generally specified in volts and amperes, while that of the core is specified in flux density units, such as flux lines per square inch, and magnetomotive force units, such as ampere-turns per inch.

A modification of the invention in the form of a current transformer is shown diagrammatically in Fig. 4. This utilizes similar members to those shown in Fig. 2, with the addition of the following parts: part 23, which is a "through" conductor, such as the central conductor of a high voltage bushing, passing through the windows of the two core parts and serving as a one-turn primary winding for the inductor which now acts as a current transformer; part 24, which is an instrument burden in the output circuit of coils 10 and 11 now serving as the secondary winding of the current transformer; part 25, which is a compensatory impedor; part 26, which is an auto-transformer, preferably with a plurality of fine tap steps, interposed between the secondary winding of the current transformer and its instrument burden to make a precise adjustment of the magnitude of the burden current to the desired value, and conductors 27 and 28, which together with conductor 23 are the line conductors of a three-phase circuit. Other parts are those described in connection with Fig. 2.

A one-turn-primary current transformer is called a bushing-type current transformer. This type of construction has many advantages over other types of construction for current transformers in compactness, convenience, and economy, but it is inherently less accurate than they, frequently not sufficiently accurate for metering, and some times not accurate enough even for high-grade relaying purposes. Its use in industry has, therefore, been limited. The accuracy of such a device varies with the maximum current for which it is designed (better with the larger currents and poorer with the smaller ones), whereas the other common types, with primary windings adaptable to any favorable number of turns, are not so affected over a wide range of currents. Thus, in the higher-voltage (and therefore lower-current) systems where the bushing-type current transformer would be particularly welcome for its convenience, economy and ease of insulation, it tends to become unusable for lack of sufficient accuracy.

Many attempts have been made in the past to improve the accuracy of this type of device. One such scheme is that described by the present applicants in U. S. Patent 1,706,139 which is assigned to the assignee of this application. In that patent the current transformer core is subjected

to auxiliary magnetization at a frequency high compared with the frequency of the current to be measured so as to reduce the excitation losses and the attendant errors to a minimum. While the invention did prove beneficial in laboratory tests, it did not find any commercial acceptance. The principle of that invention required that the auxiliary excitation have a relatively high frequency of the order of at least seven times that of the current to be measured. But a source of electrical current of any type of design, for sevenfold commercial frequency, whether a rotating machine or a static device, proved expensive and also involved problems of attendance or control. Furthermore, the maximum improvement gained in that system was satisfactory only when the deficiency in accuracy of the conventional device was not very large.

As contrasted with our prior patent which attempted to secure the desired accuracy through the reduction of the excitation volt-amperes, our present invention is based instead on the linearization of the volt-ampere curve, preferably in conjunction with compensatory means for the linearized curve. In this latter scheme, not only no reduction of the wattless component is required, but not even a reduction of the watt component is required, linearization being the only essential. Generally it will be found, however, that in the attempt for linearization, some incidental reduction of both components is unavoidable. While such reduction is not harmful in this application, and even beneficial, the fact that it is only incidental to the scheme makes it necessary or more desirable to use a different frequency, or a different flux density, or both a different frequency and a different flux density, for the auxiliary excitation. For instance, while in the prior scheme at least a sevenfold frequency auxiliary excitation was necessary (though not necessarily sufficient) for the required watt and volt-ampere reduction, in the present scheme triple frequency is found effective for the required linearization as illustrated in Fig. 3. In general, the linearization of the operating-frequency excitation characteristic does not, nor is it intended to, render the current transformer errors negligible or tolerable, and serious ratio and phase angle errors may be expected after the linearization is accomplished. These errors, however, will now be constant by virtue of the linearization of the excitation curve and may be corrected or compensated for as follows:

The phase-angle error is corrected or compensated for by impedor 25, which may be a resistor, or an inductor, or a capacitor, or a combination thereof, depending on the power factor of the burden 24 and the power factor of the lower-frequency excitation volt-amperes of the core. In the particular device on which the data in Table I below is based it was a resistor in series with an inductor. The ratio error is corrected or compensated for by the tapped auto-transformer 26.

In carrying out the improvement of the phase-angle error by a convenient impedor 25 a ratio error that is already bad may become worse. This, however, entails no difficulty in the present invention, because the error is constant and otherwise corrigible, and therefore the practically best possible phase-angle correction may be carried out using the most convenient impedor 25. Then the resulting ratio error, whatever it may be, large or small, is corrected by means of the auto-transformer 26 which is provided with plu-

rality of taps in fine steps for a precise adjustment of the burden current ratio for any given burden.

The fact of the linearity of the magnetization curve and the resulting practicability of correcting large ratio errors by the indicated means, effective for a wide range of currents, offers another advantage in that the impedor 25 need not be confined to a specific power factor in any given case, but a considerable range of power factors is permissible for it, all of them capable of providing adequate phase-angle correction, though with varying effects on the ratio error. The range of choice and the ease of adjustment of impedor 25 for the phase-angle correction is thus very much simplified.

As an illustration, a current transformer for a 69,000 volt 100-ampere bushing, constructed in accordance with the present invention, to step down the bushing current from 100-amperes to 5-amperes in the secondary burden, had the constants and characteristics exhibited in Table I below.

TABLE I
69,000 volt current transformer

100 : 5 amps. (20 secondary turns)
Burden 15 volt-amperes at 0.9 power factor
(2) Cores, each 10% ID x 12% OD x 5 1/4" high

Total core weight=100 lbs.
Part No. 25, Z=19.4 + 23.2 ohms
Part No. 26, turn ratio=1.02 : 1

Sec. Amps.	Plain C-T		H-F Exc. Added		Part 25 Also Added		Complete with Part 26 Also Added	
	RCF	β	RCF	β	RCF	β	RCF	β
.5	Off Scale	Off Scale	1.0215	+25	1.0184	+3	1.0005	+5
1.0	do	do	1.0216	+26	1.0184	+3	1.0004	+4
3.0	1.082	216'	1.0211	+21	1.0180	-1	1.0003	+1
5.0	1.068	156'	1.0212	+16	1.0180	-5	1.0004	-2

In this table, RCF means ratio correction factor, and β represents the phase-angle error of the current transformer. "Off scale" in this table means greater than 1.10 for the RCF, and greater than 420 minutes for β , these figures being the maximum errors measurable by the test equipment used. An RCF of 1.10 is equivalent to saying that the secondary current is 10 per cent too low. It will be seen in this tabulation that at full rated current, that is, at five-ampere secondary current, the ratio error was 6.8 per cent for the plain current transformer, 2.12 per cent when triple-frequency excitation was added at 25,000 lines per square inch, and 0.04 per cent, or 1/25 of one per cent, when the ratio and phase-angle compensations also were added. That is, the triple-frequency excitation reduced the ratio error in the proportion of 3.2:1, and the other compensations reduced it further in the ratio of 53:1. Comparing the 3.2:1 improvement with the 53:1 improvement, it is seen that the reduction of the exciting current by the auxiliary excitation, though beneficial in this case, is a minor and incidental factor in the error reduction.

The linearization of the magnetization curve by this auxiliary excitation is made strikingly clear by the constancy of the second RCF column up to four significant figures, while the first RCF column is constant to only one significant figure.

Attention may also be called to the impressive improvements in the phase-angle error. At the rated current, this error is reduced from +156 minutes to -2 minutes. In general, a phase-angle error of plus or minus 5-10 minutes is considered within metering accuracy.

In the current transformer of Table I, part 25

for the phase-angle correction consisted of a 19.4 ohm resistor in series with a 23.2 ohm inductive reactor, while the auto-transformer had a primary to secondary turn ratio of 1.02:1.

Although in Fig. 4 the phase-angle correction impedor 25 is shown as connected directly across the secondary winding of the transformer, it obviously could also be connected across a tap of the auto-transformer or even a separate winding on the auto-transformer core, so as to render the adjustment of the compensation very convenient.

While there have been shown and described particular embodiments of the invention, it will be obvious to those skilled in the art that various changes and modifications can be made therein without departing from the invention, and, therefore, it is aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

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

1. An electromagnetic induction apparatus including in combination, a ferro-magnetic core, a

main winding adapted to carry alternating current and linking said core so as to magnetize said core, an auxiliary winding adapted to carry alternating current and linking said core so as to magnetize said core, said auxiliary winding being arranged non-inductively with respect to said main winding, and means for circulating alternating current through said auxiliary winding at a frequency higher than the frequency of the alternating current in said main winding and of a magnitude to render the volt-ampere excitation characteristic of said main winding substantially linear, said current in said auxiliary winding being substantially less than necessary to reduce said volt ampere excitation of said main winding to a minimum.

2. An electromagnetic induction apparatus including in combination, a ferro-magnetic core, a main winding adapted to carry an alternating current which is variable over a predetermined normal range, said main winding linking said core so as to magnetize said core, an auxiliary winding adapted to carry alternating current and linking said core so as to magnetize said core, said auxiliary winding being arranged non-inductively with respect to said main winding, and static frequency tripling means for circulating a substantially constant alternating current through said auxiliary winding at a frequency of three times the frequency of the alternating current in said main winding and of a magnitude to render the volt-ampere excitation characteristic of said main winding substantially linear throughout its normal range of operation, the triple frequency flux density produced by said auxiliary winding being greater than the maximum flux density produced

by said main winding in the normal operating range of the variable alternating current in said main winding, said current in said auxiliary winding being substantially less than necessary to reduce said volt ampere excitation of said main winding to a minimum.

3. An electromagnetic induction apparatus including in combination, a ferro-magnetic core, a main winding adapted to carry an alternating current which is variable over a predetermined normal operating range, said main winding linking said core so as to magnetize said core, an auxiliary winding adapted to carry alternating current and linking said core so as to magnetize said core, said auxiliary winding being arranged non-inductively with respect to said main winding, and static frequency tripling means for circulating a substantially constant alternating current through said auxiliary winding at a frequency of three times the frequency of the alternating current in said main winding and of a magnitude to render the volt-ampere excitation characteristic of said main winding substantially linear throughout its normal range of operation, the triple frequency flux density produced by said auxiliary winding being in the neighborhood of the maximum permeability zone of said core and being greater than the maximum flux density produced by said main winding in the normal operating range of the variable alternating current in said main winding.

4. In combination, a ferro-magnetic core, a main winding adapted to carry an alternating current which is variable over a predetermined normal operating range, said main winding linking said core so as to magnetize said core, an auxiliary winding adapted to carry alternating current and linking said core so as to magnetize said core, said auxiliary winding being arranged non-inductively with respect to said main winding, static frequency tripling means for circulating a substantially constant alternating current through said auxiliary winding at a frequency of three times the frequency of the alternating current in said main winding and of a magnitude to render the volt-ampere excitation characteristic of said main winding substantially linear throughout its normal range of operation, the triple frequency flux density produced by said auxiliary winding being in the neighborhood of the maximum permeability zone of said core and being greater than the maximum flux density produced by said main winding in the normal operating range of the variable alternating current in said main winding, and a constant impedor connected to said main winding for compensating for the effective impedance of said main winding.

5. In combination, a ferro-magnetic core, a main winding adapted to carry an alternating current which is variable over a predetermined normal operating range, said main winding linking said core so as to magnetize said core, an auxiliary winding adapted to carry alternating current and linking said core so as to magnetize said core, said auxiliary winding being arranged non-inductively with respect to said main winding, static frequency tripling means for circulating a substantially constant alternating current through said auxiliary winding at a frequency of three times the frequency of the alternating current in said main winding and of a magnitude to render the volt-ampere excitation characteristic of said main winding substantially linear throughout its normal range of operation, the triple frequency flux density produced by said

auxiliary winding being in the neighborhood of the maximum permeability zone of said core and being greater than the maximum flux density produced by said main winding in the normal operating range of the variable alternating current in said main winding, and a capacitor connected to said main winding so as to produce a circuit which is resonant over a wide range of current and voltage.

6. A bushing-type current transformer comprising in combination, a ferro-magnetic core, a main primary winding adapted to carry an alternating current which is variable over a predetermined normal operating range, said main primary winding linking said core so as to magnetize said core, an auxiliary winding adapted to carry alternating current and linking said core so as to magnetize said core, said auxiliary winding being arranged non-inductively with respect to said main primary winding, static frequency tripling means for circulating a substantially constant alternating current through said auxiliary winding at a frequency of three times the frequency of the alternating current in said main primary winding and of a magnitude to render the volt-ampere excitation characteristic of said main winding substantially linear throughout its normal range of operation, the triple frequency flux density produced by said auxiliary winding being in the neighborhood of the maximum permeability zone of said core and being greater than the maximum flux density produced by said main winding in the normal operating range of the variable alternating current in said main primary winding, and a main secondary winding linking said core and being arranged inductively with respect to said main primary winding and non-inductively with respect to said auxiliary winding.

7. A bushing-type current transformer comprising in combination, a ferro-magnetic core, a main primary winding adapted to carry an alternating current which is variable over a predetermined normal operating range, said main primary winding linking said core so as to magnetize said core, an auxiliary winding adapted to carry alternating current and linking said core so as to magnetize said core, said auxiliary winding being arranged non-inductively with respect to said main primary winding, static frequency tripling means for circulating a substantially constant alternating current through said auxiliary winding at a frequency of three times the frequency of the alternating current in said main primary winding and of a magnitude to render the volt-ampere excitation characteristic of said main winding substantially linear throughout its normal range of operation, the triple frequency flux density produced by said auxiliary winding being in the neighborhood of the maximum permeability zone of said core and being greater than the maximum flux density produced by said main winding in the normal operating range of the variable alternating current in said main primary winding, a main secondary winding linking said core and being arranged inductively with respect to said main primary winding and non-inductively with respect to said auxiliary winding, and an impedor connected to one of said main windings and being proportioned to provide substantial compensation for the phase angle error of said current transformer.

8. The combination defined in claim 10 in which said impedor is resistive and reactive.

9. The combination as defined in claim 10 in which said impedor is inductive.

10. A bushing-type current transformer comprising in combination, a ferro-magnetic core, a main primary winding adapted to carry an alternating current which is variable over a predetermined normal operating range, said main primary winding linking said core so as to magnetize said core, an auxiliary winding adapted to carry alternating current and linking said core so as to magnetize said core, said auxiliary winding being arranged non-inductively with respect to said main primary winding, static frequency tripling means for circulating a substantially constant alternating current through said auxiliary winding at a frequency of three times the frequency of the alternating current in said main primary winding and of a magnitude to render the volt-ampere excitation characteristic of said main winding substantially linear throughout its normal range of operation, the triple frequency flux density produced by said auxiliary winding being in the neighborhood of the maximum permeability zone of said core and being greater than the maximum flux density produced by said main winding in the normal operating range of the variable alternating current in said main primary winding, a main secondary winding linking said core and being arranged inductively with respect to said main primary winding and non-inductively with respect to said auxiliary winding, an impedor connected to one of said main windings and being proportioned to provide substantial compensation for the phase angle error of said current transformer, and means for reducing the ratio error of said current transformer.

11. The combination as recited in claim 10 in which the means for reducing the ratio error is an auto-transformer having input terminals connected to said main secondary winding and

having output terminals for connection to a burden.

12. Apparatus for linearizing the magnetization characteristic of a fundamental frequency variable alternating current energized iron cored inductance which comprises, a source of higher harmonic frequency alternating current, and means connected to said source for superposing an additional higher frequency alternating magnetization on the core of said inductance, the magnitude of said additional magnetization being of the order of one-tenth the value which will produce minimum fundamental frequency core loss.

13. In combination, an iron cored current transformer having primary and secondary windings, and means for making constant the ratio error of said current transformer over a substantial range of fundamental frequency primary current which comprises, a source of triple frequency current, and means connected to said source for providing auxiliary triple frequency magnetization of the core of said current transformer core at such a value as to linearize its fundamental frequency magnetization characteristic over said range.

GUGLIELMO CAMILLI.
ARAM BOYAJIAN.

REFERENCES CITED

The following references are of record in the file of this patent:

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Number	Name	Date
1,157,730	Spinelli	Oct. 26, 1915
1,706,139	Boyajian et al.	Mar. 19, 1929

Certificate of Correction

Patent No. 2,467,807.

April 19, 1949.

GUGLIELMO CAMILLI ET AL.

It is hereby certified that errors appear in the printed specification of the above numbered patent requiring correction as follows:

Column 10, line 72, claim 8, and line 74, claim 9, for the claim reference numeral "10" read 7;

and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 25th day of October, A. D. 1949.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.

Certificate of Correction

Patent No. 2,467,807.

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It is hereby certified that errors appear in the printed specification of the above numbered patent requiring correction as follows:

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Signed and sealed this 25th day of October, A. D. 1949.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.