

Oct. 26, 1954

J. A. BARING

2,692,969

DUAL SECONDARY SIGNAL TRANSFORMER

Filed May 11, 1950

2 Sheets-Sheet 1

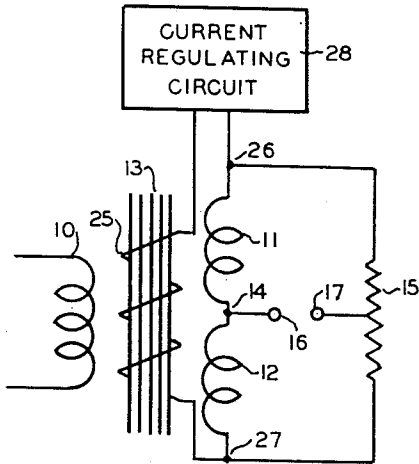


FIG. 1

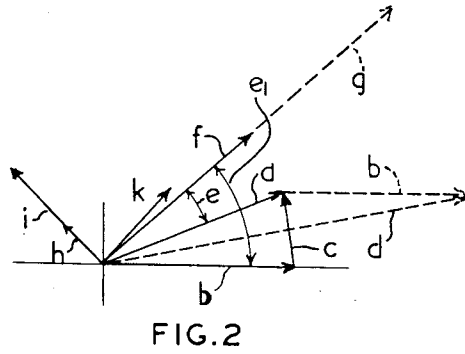


FIG. 2

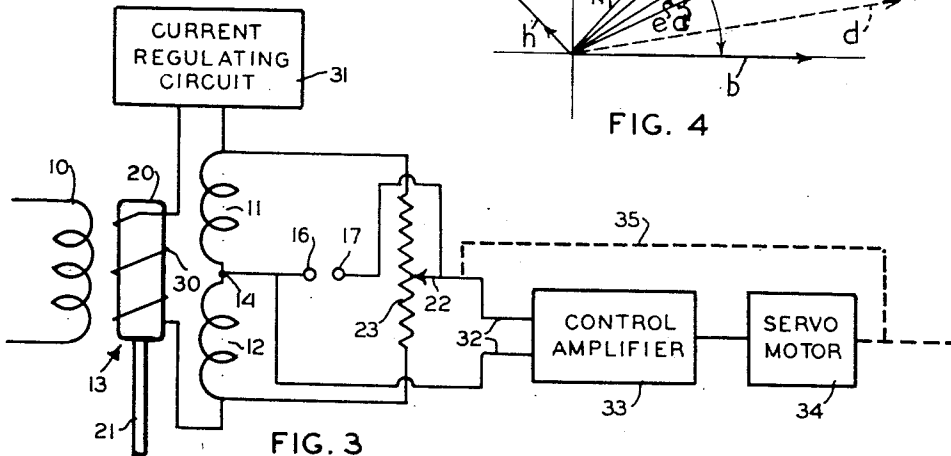


FIG. 3

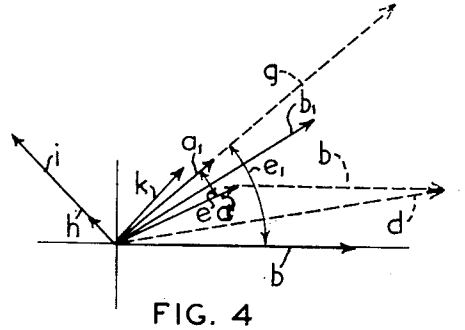


FIG. 4

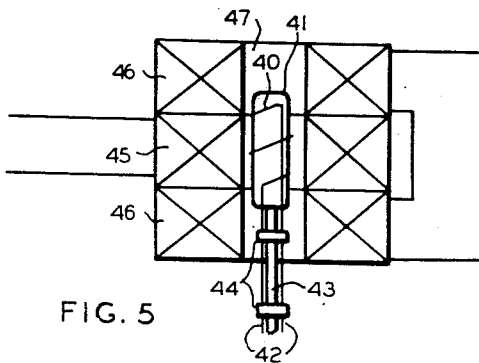


FIG. 5

JOHN A. BARING  
INVENTOR.

BY *Henry R. Foster*  
*James B. Rizer*  
ATTORNEYS

Oct. 26, 1954

J. A. BARING

2,692,969

DUAL SECONDARY SIGNAL TRANSFORMER

Filed May 11, 1950

2 Sheets-Sheet 2

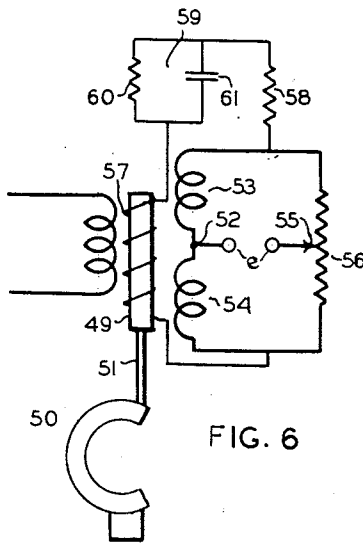


FIG. 6

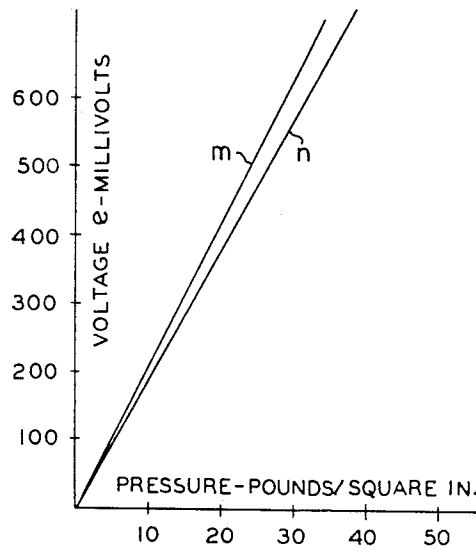


FIG. 7

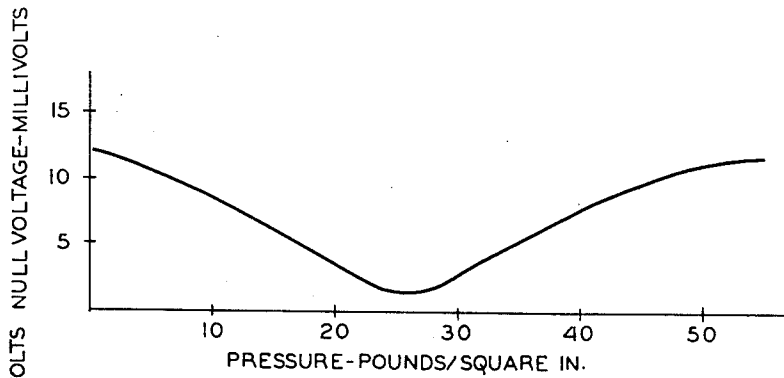


FIG. 8

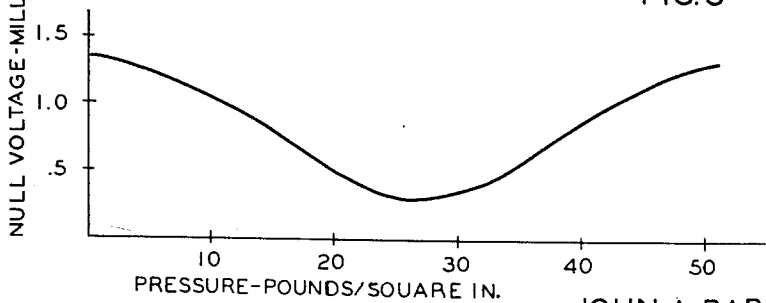


FIG. 9

JOHN A. BARING  
INVENTOR  
BY *[Signature]*  
*[Signature]*  
ATTORNEYS

## UNITED STATES PATENT OFFICE

2,692,969

## DUAL SECONDARY SIGNAL TRANSFORMER

John A. Baring, Evanston, Ill., assignor to Askania  
Regulator Company, Chicago, Ill., a corpora-  
tion of Illinois

Application May 11, 1950, Serial No. 161,455

6 Claims. (Cl. 323—48)

1

The present invention relates to transformers of the type having a secondary winding system divided into two distinct parts or sections by an output terminal, and a core of magnetically permeable material inductively coupling such secondary system with a primary winding. A very useful arrangement of such a transformer comprises provision for relative movement between the core and secondary winding system, so that degree of coupling of the respective parts of the secondary system; and consequently the relative amplitudes of voltages induced in such parts respectively may be selected by appropriate positioning of the core relative to such windings or parts. By such an arrangement the intermediate output terminal of the secondary system can be used as a voltage reference point, and between such point and the opposite ends of the secondary system can be obtained voltages of opposite phase sense and of amplitudes depending on the position of the core relative to the secondary system parts. By applying such voltages to the opposite ends of an impedance provided with an intermediate tap, a signal voltage may be developed between the respective intermediate taps of the secondary system and impedance. The arrangement presents several possibilities for signal voltage development. The intermediate tap of the impedance may be fixed, as at the electrical center point of the impedance, and the signal voltage developed between it and the intermediate output terminal of the secondary system, which also is assumed to be a center tap, will correspond in phase sense to the direction of deflection of the core piece from a neutral or zero position wherein the voltages induced in the respective secondary system parts are of equal amplitudes, the amplitude of such signal voltage being proportional to degree of such deflection of the core piece from its neutral position. The intermediate tap of the impedance may be variable, and adjustable to balance out the signal by variation of the voltage point of the impedance to produce a tap voltage equal in amplitude to that of the secondary output terminal, again assumed to be a center tap. In the latter type of arrangement the adjustment of the variable tap, or the ratio of impedance values lying to opposite sides of it when its output voltage balances that of the secondary tap, provides a measure of the position of the magnetically permeable core piece.

These variable dual secondary transformers have proven extremely valuable for use as signal sources for translation of mechanical signals to corresponding alternating signal voltages. Such

2

mechanical signals are applied to move the core piece to a distance from a selected zero position corresponding to signal magnitude. Connection of the secondary system to an impedance having a variable intermediate tap, in the manner described above, provides a bridge type signal voltage system the output of which, taken across the respective intermediate taps of the secondary system and impedance, may effectively be applied to a null circuit constituting the signal input to a control amplifier that is selectively responsive to alternating voltage of either phase sense. Such control amplifier may be used to drive a servomotor, and if such motor be connected to drive the variable tap of the impedance in usual signal-canceling arrangement to proportion motor operation to magnitude of unbalance of the bridge, an effective motor position control is established.

There are commercially available signal transformers of the dual secondary and movable core type that are very satisfactory insofar as response of secondary voltage amplitudes to core piece position change alone is concerned, such transformers having very nearly linear characteristics of response of variation of secondary voltage with change of core piece position. These transformers, however, are subject to appearance of disturbance voltages that appear when the voltages induced in the respective parts of the secondary system are of equal amplitudes, and that also appear in the bridge type arrangement provided with a variable impedance having an intermediate tap, when such tap is adjusted so that its voltage amplitude equals the voltage amplitude at the secondary output terminal, which should result in complete balancing out of voltage between such tap and terminal. These voltages, hereinafter termed "null voltages" because of their appearance in conditions of theoretical voltage balance, appear substantially in quadrature phase relation to the voltage across the entire secondary system, or resultant of the respective secondary voltages on opposite sides of the secondary intermediate output terminal. They appear at minimum amplitude in the neutral position of the core piece, wherein voltages of equal amplitudes are induced in the respective parts or sections of the secondary winding system, and increase in somewhat irregular functional relation with deflection of the core piece from that position in either direction, and accompanying variation in relative amplitudes of the voltages induced in the respective parts of the secondary system.

Null voltage characteristics of dual secondary transformers, and especially dual secondary transformers having movable core pieces for variation of secondary output voltage amplitude, heretofore have unduly limited the types of service of such transformers. If such a transformer is used as a source of signal voltage for a direct-current amplifier, the null voltage constitutes a false signal if its amplitude range is in the response sensitivity range of the amplifier. While false signal effects of null voltage can be eliminated by employing a properly phased alternating current amplifier, such voltage tends to load or saturate the amplifier, seriously impairing its sensitivity, and in certain cases serving to restrict the useful range of transformer output voltage to a very limited region in the immediate neighborhood of the neutral position of the transformer core piece and wherein the null voltage amplitude is within the saturation tolerance limit of the amplifier. The present invention is devoted to the problem of reducing null voltage substantially and at least to a level that will materially extend the fields in which transformers of the type in question are practically useful.

Null voltage, which as stated appears in quadrature phase relation with the total voltage across the entire secondary system of a dual secondary transformer, appears to arise from, or at least to accompany, variance from phase agreement between the respective secondary voltages, such phase disagreement apparently being of minimum degree when the amplitudes of the respective secondary voltages are equal, and increasing with movement of the core piece from the position productive of such equal voltage amplitudes. It is evident that such core piece deflection is accompanied by change in the degree of coupling between the respective secondary windings and the primary winding. The presence of null voltage at the neutral position of the core piece, wherein the amplitudes of the respective secondary voltages are equal, may arise from either or both an actual inequality of coupling of the respective secondary windings with the primary winding when the core piece has been adjusted to a position productive of equal secondary voltage amplitudes, possibly arising from unavoidable differences in the electrical characteristics of the respective secondary windings, and/or non-uniformity of the physical structure of the core piece resulting in non-uniform magnetic characteristics and in variance between intensities of magnetic field portions interlinked with the two windings in closer and more remote degrees. Whatever may be the true cause of null voltage, a corrective measure applied to the respective secondary windings in general proportional relation to the closeness of their respective couplings with the primary winding, or to the respective amplitudes of voltages induced in them when the core piece is out of its neutral position, and of a character tending to shift the respective secondary voltages toward a common phase, results in a marked reduction of null voltage, both at the neutral core piece position and throughout the range of core piece position variation, as will be described fully in the following disclosure.

A primary object of the invention is the provision in a dual secondary transformer having a magnetically permeable core piece so positioned relative to the respective secondary windings as to induce in them voltages of equal amplitudes, of a novel arrangement for reducing substan-

tially the amplitude of null voltage appearing substantially in quadrature phase relation with the voltage appearing across the secondary system.

Another primary object of the invention is the provision in a dual secondary transformer having a movable core piece, of novel means for reducing throughout the range of variation of such core piece the corresponding amplitude range of such null voltage.

Another object is the provision in a dual secondary transformer, of novel means for reducing phase disagreement between voltages induced in the respective secondary windings.

Another object is the provision in a dual secondary transformer that is provided with a movable core piece for varying inversely the voltages induced in the respective secondaries, of novel means for substantially reducing adverse effects on the output of the secondary system accompanying movement of the core piece.

Still another object is the provision of a novel arrangement of center tapped secondary, variable transformer, capable of highly satisfactory use in a null circuit bridge arrangement with a signal canceling impedance connected across the transformer secondary system and having a variable intermediate tap providing voltage for comparison with the secondary center tap voltage for development of an error signal.

A further object is the provision of a dual secondary transformer, with novel means for applying to the respective secondary windings corrective voltages the effects of which on the respective secondary voltages induced from primary current automatically are proportioned to adverse effects on such voltages accompanying different degrees of closeness of coupling of the secondary windings with the primary winding.

In the accompanying drawings:

Fig. 1 is a schematic diagram illustrating a basic and broad aspect of the invention, disclosing its application to a dual secondary transformer having a core piece disposed for induction of voltages of equal amplitudes in the respective secondary windings.

Fig. 2 is an exaggerated vector diagram disclosing a theory of production of null voltage in an arrangement such as that of Fig. 1, and also illustrating the mode of performance of the invention, and a theory of its mode operation.

Fig. 3 is a schematic diagram disclosing application of the invention to a variable dual secondary transformer used as a source of variable and reversible phase sense alternating voltage in a null circuit bridge arrangement constituting the signal circuit of a servomotor position control system.

Fig. 4 is a vector diagram similar to Fig. 2 and illustrating the method of performing the invention and a theoretical mode of its operation, as applied to a variable dual secondary transformer.

Fig. 5 is a schematic median section of a variable dual secondary transformer embodying a form of the invention.

Fig. 6 is a schematic diagram disclosing use of the invention in a system for measuring pressure magnitude by means of a variable dual secondary transformer.

Fig. 7 is a graphical diagram disclosing the sensitivities of the same transformer, arranged in the system of Fig. 6, respectively with and without employment of the invention.

Figs. 8 and 9 are graphs, both greatly enlarged

5

with respect to the scale of Fig. 7, and further respectively enlarged vertically by greatly different factors, disclosing null voltage ranges of the same transformer, connected as in Fig. 6, and respectively without and with application of the invention.

Describing the drawings in detail and first referring to Fig. 1, a transformer is disclosed as having a primary winding 10, a pair of secondary windings 11, 12 and a core 13 of magnetically permeable materials inductively coupling the respective secondary windings to the primary winding. It is assumed that the relative positional relations between the respective secondary windings and the core piece are such that voltages of equal amplitudes are induced in the respective secondary windings by current flowing in the primary winding 10. The windings 11, 12 are shown as connected in series aiding relation, and an output terminal or center tap 14 is connected between them to serve as a voltage reference point. The electrically opposite ends of the respective secondary windings 11, 12, that is to say the opposite ends of the secondary winding system, are shown connected to opposite ends of a center tapped resistance 15.

This arrangement, which is shown principally for purposes of disclosure and explanation of one aspect of the invention, is such that no voltage should appear across terminals 16, 17, respectively connected with the secondary center tap 14 and the center tap of resistance 15, since both constitute midpoints between voltages that are equal and opposite. Actually, however, a voltage does appear across these terminals, such being the null voltage referred to above, and appearing in phase quadrature relation to the resultant voltage of the two secondary windings, appearing across the entire secondary winding system.

Referring now to Fig. 3, the same reference numerals are applied to the transformer windings as in Fig. 1. In Fig. 3 the magnetically permeable core comprises a core piece 20, movable by a rod 21 in directions parallel to the axes of the various windings for varying the closeness of coupling of the respective secondary windings 11, 12, with primary winding 10, thereby to select the amplitudes of voltages induced in them respectively by current flowing in the primary winding. In Fig. 3, the terminal 17 is connected to the variable contact or tap 22 of a potentiometer, the resistance 23 of which is connected between the electrically opposite ends of the respective secondary windings 11, 12, in other words across the secondary system of the transformer. In this type of arrangement, with the core piece displaced from its neutral position it is theoretically possible to move the potentiometer tap 22 to a corresponding position wherein no voltage will appear across terminals 16, 17 it being possible to adjust the position of contact 22 to a point on resistance 23 at which no potential exists between such tap and center tap 14 of the secondary winding system. Actually, even though the potentiometer tap 22 is moved to such a position that the voltages across the parts of resistance 23 are respectively equal in magnitude to the voltages induced in the respective secondary windings, a null voltage will appear across terminals 16, 17. Such voltage, as stated in the preliminary part of this specification, varies in somewhat irregular functional relation with displacement of the core piece from its neutral position.

6

The vector diagrams, Figs. 2 and 4, respectively disclose a possible explanation of null voltage and the functional relation that its amplitude bears to core piece position change. These vector diagrams also illustrate the manner in which null voltage-reducing or corrective voltages are applied to the respective secondary windings, and a possible explanation of their effectiveness in reduction of null voltage.

Referring first to Fig. 2, vector *a* represents the voltage induced by primary current in one of the secondary windings, as 11, of Fig. 1, and vector *b* represents the voltage induced in the other secondary winding. The appearance of a null voltage across terminals 16, 17 reasonably is explained as the result of the indicated phase lag by vector *b* of vector *a*, resulting in the appearance of a quadrature voltage represented by vector *c*, and that is of amplitude proportional to both amplitudes of the respective secondary voltages and degree of phase displacement between them. Actually, the phase lag and magnitude of quadrature null voltage are greatly exaggerated in the vector diagrams Figs. 2 and 4. The resultant of the two secondary voltages, or the total voltage appearing across the secondary winding system is represented by the dotted vector *d*.

In its broadest aspect, the invention resides in applying to the respective secondary windings corrective voltages of a common phase, but of different amplitudes, each having an out of phase relation to the secondary voltage induced from primary current in the secondary windings to which it is applied and therefore tending to shift the latter voltages in the same direction but to different degrees as determined by such voltage amplitudes. The theory of this procedure is that the amplitudes of such corrective voltages are roughly proportioned to degree of displacement of the respective secondary voltages from a common phase and therefore have a tendency to shift such voltages different degrees and into much closer phase correspondence.

As a means of generally proportioning the relative amplitudes of corrective voltages to the different null voltage-producing effects that act in the respective secondaries, and based on the theory that such effects arise from or accompany different degrees of closeness of coupling of the respective secondaries with the primary winding, and therefore are functionally related to relative number of interlinkages between the magnetic field of the core and the turns of the respective secondary windings, the corrective voltages conveniently are applied to the secondaries by inducing them in the secondary windings through interlinkages with the respective secondary windings of an auxiliary magnetic field developed at the core, the numbers of such interlinkages with the respective secondaries having similar proportional relation to that existing between the respective secondary windings and the core field generated by primary current.

Referring again to Fig. 1, it will be seen that an auxiliary primary winding 25 is inductively coupled with the secondary windings 11, 12 through core 13, such winding being shown as encircling the core so that upon energizing auxiliary winding 25 by alternating current, auxiliary voltages in the respective secondary windings 11, 12 are induced from such current. It will be seen that if the auxiliary voltages can be made to have on the principal secondary voltages corrective effects that tend to counteract whatever difference in the characteristics of the two windings

is responsible for null voltage, their application should result in null voltage reduction. It has been found that proper phasing, with respect to secondary voltage, of alternating current used to energize an auxiliary primary winding arranged as in Fig. 1, actually results in a marked reduction of null voltage.

A corrective effect is given the auxiliary voltages induced in the respective secondaries by so phasing such voltages relative to the principal secondary voltages that the latter tend to be shifted in phase in a common direction, and it is my theory that since the auxiliary voltages are induced in the respective secondaries through interlinkages of the latter with the auxiliary core field, the degree of phase shift of the respective secondary voltages accomplished by the auxiliary voltages is related to the unequal interlinkages of the respective secondaries with the main core field, or with relative closeness of the respective secondaries with the primary that are responsible for, or accompany null voltage production.

Again referring to Fig. 2 it will be seen that if the phases of the secondary voltages respectively represented by vectors  $a$  and  $b$  can be advanced respectively by degrees represented by angles  $e$  and  $e_1$ , the respective voltages can be brought into phase agreement, as represented by vector  $f$ , so that vectors representing them are colinear with each other and therefore with their resultant  $g$ , and no quadrature or null voltage appears. Corrective voltages for accomplishing these phase shifts are represented by vectors  $h$  and  $i$ , such voltages being in phase agreement and leading the resultant of the principal secondary voltages by a substantial angle, as indicated by the angular position of the vectors that represent them. Empirical experiment has indicated that a slight leading phase angle of current used to energize the auxiliary primary winding, with respect to phase of the voltage across the secondary system, is productive of the best null voltage reduction effect. Actually, and regardless of theory of mode of its accomplishment, the provision of an auxiliary primary winding arranged as in Fig. 1 and energized by a current having a phase relation to voltage across the secondary system of a dual secondary transformer of a slightly leading character, somewhat as represented by the relation of vector  $k$  of Fig. 2 to vector  $g$ , results in a null voltage reduction of approximately eighty-eight percent, as will later be described in detail.

Production, and correct phasing of the current that energizes the auxiliary primary winding, conveniently and practically can be accomplished by developing it from voltage appearing across the secondary winding system. As shown in Fig. 1, the winding 25 may be coupled parallel to the secondary winding system, by a circuit having its input terminals 26, 27 connected to the opposite sides of the secondary system. For proper phasing of the current energizing winding 25 relative to the voltage appearing across the secondary winding system 11, 12, and for regulating amplitude of such current, a current regulating system 28 may be connected in the circuit with winding 25, and may include any conventional phase and amplitude selective arrangements.

In Fig. 3, an auxiliary primary winding 30 is shown mounted on, and movable with the movable core piece 20. This auxiliary primary winding 30 is energized by voltage developed across the entire secondary system of the transformer,

and the phase and amplitude of current supplied to it is selected by a current regulating system 31. It has been found that an arrangement of this kind results in null voltage reduction, throughout the entire range of core piece position variation wherein variation of secondary voltage amplitude is linear, of approximately the same degree as mentioned above in the neutral condition of transformers of the kind in question, namely a reduction of approximately eighty-eight percent as compared to the null voltage range of the same transformers when not provided with compensating or correcting auxiliary primary windings.

Fig. 4, which is quite similar to Fig. 3, represents voltage relations in a variable dual secondary transformer in an unbalanced condition resulting from deflection of its core piece from its neutral position. In such variable transformers, the null voltage characteristic, as stated above, has an irregular functional relation to degree of core piece deflection. This is partly explainable as being the result of increasing variance between the inductances of the respective secondary windings as their relative interlinkage with the core field are altered, and is advanced as supporting the theory that in the neutral condition of a dual secondary transformer null voltage results from actually different degrees of such interlinkages of the respective secondaries with the core field, and a resulting variance in their inductances and a phase disagreement between their voltages. It is believed that the increased null voltage that appears when the core piece is displaced from neutral position accompanies increased phase disagreement between the secondary voltages. Such an increased phase disagreement is represented by an angle between vectors  $a$  and  $b$ , which again represent the respective secondary voltages, as compared with the corresponding angle of Fig. 1. It will be seen that this increased phase angle results in a marked increase in the difference between angles  $e$  and  $e_1$  that separate the respective vectors  $a$ ,  $b$  from some common angular position, such as that of vector  $g$  and representing phase agreement of the secondary voltages, and consequently in a greater differential in amplitudes of corrective voltages that are necessary to advance the two secondary voltages to such a phase agreement relation. However, it is to be noted that the greater lag of vector  $a$  by vector  $b$  represents the effect on the corresponding voltages of the same core piece deflection that also relatively increases the amplitude of voltage  $b$ , while the corresponding decrease in coupling of the other secondary responsible for decreased amplitude of its voltage may result in a decrease of its lag from a common leading phase. Consequently, since the corrective or phase advancing auxiliary voltages are induced in the respective secondaries through similarly unequal couplings that are responsible for the relative phase variation between the voltages of the two secondaries, and since amplitudes of such auxiliary voltages and their respective phase-advancing effects are related to such unequal couplings, the phase advancing effects of the auxiliary voltages on the principal secondary voltages automatically are related to the respective angle through which such voltages must be shifted to reach phase agreement, and the corrective effects applied to the two secondaries automatically are related to the need for them throughout the variation range of the transformer.

Thus in Fig. 4, the amplitude of the corrective voltage represented by vector  $h$ , which is assumed to be induced in the secondary that produces voltage  $a$ , is reduced as compared to the corresponding voltage of Fig. 2, and the amplitude of voltage  $i$  is correspondingly increased, these amplitude relations accompanying the differential in interlinkage with the auxiliary core field of the secondaries respectively producing voltages  $a$  and  $b$ . Instead of the perfect phase agreement suggested by Fig. 1 between the two shifted secondary voltages, in Fig. 4 vectors  $a$  and  $b$  respectively have been shifted by degrees of such magnitude that the vectors are still out of phase but wherein they are in much closer phase than in their original relation. Existence of this condition may explain the residual null voltage, varying with transformer adjustment, that occurs in the corrected system, as will appear later. The relation of the voltages, however, represents a marked improvement over the voltages of an uncorrected system.

In Fig. 3, an error signal voltage null circuit 32 is disclosed as connected across the variable potentiometer tap 22 and the secondary center tap 14. This null circuit 32 is connected as the control signal circuit of a control amplifier 33 arranged to operate a servo motor 34 in a direction to correspond to the sense of unbalance of the null circuit. A mechanical feedback or signal cancelling drive train 35 is arranged to move variable tap 22 toward a position corresponding to that of the movable transformer core piece 21 during such direction-response of the motor 34, thus constituting a well known null circuit bridge type of servo motor position control system. The contribution of the invention to this type of system will be pointed out later.

Fig. 5 discloses a simple arrangement for mounting an auxiliary primary winding on the movable core piece of a standard variable dual secondary transformer, for practicing the invention. The auxiliary winding 40 is supported directly on and surrounding the core piece 41, and is secured thereon by suitable means such as adhesive or adhesive tape. The lead wires 42 for energizing the winding may similarly be adhesively secured to the rod 43 that supports and moves core piece 41, being shown as secured to such rod by tapes 44. A standard winding arrangement of such transformers is shown, comprising in coaxial disposition a central primary winding 45 and a pair of secondary windings 46 on opposite sides of such primary winding. Core piece 41 is movable axially of the three windings in a central bore or passage 47.

Figs. 6 and 7 to 9 respectively show an actual test setup of a typical dual secondary variable transformer, and comparative graphs of the sensitivity and null voltage characteristics of the same transformer arranged in the test setup of Fig. 6 and with and without provision of such transformer with the auxiliary primary winding and system for energizing it described above with relation to Figs. 3 and 5.

In the actual test setup of the system of Fig. 6, the transformer was a commercially produced variable dual secondary transformer having a linear output voltage range of zero to eight hundred eighty millivolts, and the core piece 49 was operatively connected to the mechanical output member of a commercially produced Bourdon tube 50 having a linear response of movement of its output member to variations in applied pres-

sure through a range of zero to fifty pounds per square inch. The core piece and Bourdon tube were so positioned relative to the windings that at zero applied pressure the core piece occupied a position spaced to one side of its zero position to a degree rendering secondary voltage a linear measure of deflection of the core piece 49 from such zero position in the range of movement of the core piece by the full pressure range of the Bourdon tube. The operating and supporting stem 51 of the core piece was connected with the output element of the Bourdon tube 50. A vacuum tube voltmeter was connected across the center tap 52 of the transformer secondary winding system 53, 54 and the variable tap 55 of a potentiometer, the resistance 56 of which was connected across the secondary system of the transformer. For testing, the tap 55 was adjusted manually for balance of the null circuit between the taps 52, 55. Null voltages were measured by adjusting the potentiometer tap 55 to the minimum obtainable voltage between the taps 52, 55, at various magnitudes of pressure applied to the input of the Bourdon tube 50.

For reduction of null voltage throughout the range of variation of the transformer, an auxiliary primary winding 57 was mounted on the core piece 49, in the manner disclosed by Fig. 5. The current regulating system connected in series with auxiliary primary winding 57 included a series connected current-limiting resistance 58, and a series connected phase-adjusting network 59 also connected in series with the winding 57 and including in parallel connection a resistance 60 and a condenser 61.

Actual element values of the circuit elements, which were selected by empirical experiment giving optimum null voltage reduction, were as follows. Current-limiting resistance 58 had a resistance of seventeen hundred fifty ohms. Resistance 60 had a value of eight hundred eighty ohms, and condenser 61 a capacity of one and six-tenths microfarads. Auxiliary primary winding 57 was composed of five turns of number thirty-six copper wire. Impedance of the entire circuit was twenty-four hundred and fifty ohms at an angle of minus seven and six-tenths degrees, which was found to represent a desirable lead of the secondary voltage by the current energizing the auxiliary primary winding 57 for null voltage reduction.

The graph  $m$  of Fig. 7 represents sensitivity of the transformer without the corrective circuit, while graph  $n$  represents sensitivity of the same transformer when corrected by the circuit arranged as disclosed by Fig. 6 and as described above. Graphs  $m$ ,  $n$  were obtained by plotting as abscissae pressures exerted in the Bourdon tube and as ordinates voltage between the intermediate secondary tap 52 and the variable potentiometer tap 55 with the latter set a zero. The use of the null voltage-reducing circuit resulted in a sensitivity loss, evidenced by the lower ordinate values of graph  $n$  of approximately five percent.

The reduction of null voltage amplitudes accomplished by use of the corrective circuit disclosed by Fig. 1 and described above, is represented by the graphs of Figs. 8 and 9, which respectively represent the null voltage characteristic of the same transformer when uncorrected and when corrected by the circuit in question. It is emphasized that the vertical scale of the null voltage amplitude characteristic of the corrected transformer, shown by Fig. 9, is ten times greater

than that of the null voltage characteristic of the uncorrected transformer, disclosed by Fig. 8. Thus it will be seen that in the uncorrected transformer, null voltage increased progressively, in somewhat irregular and asymmetrical fashion from a minimum amplitude of approximately one and one-half millivolts, occurring at the neutral core piece position at the center of the pressure range, to maxima of approximately twelve and one-half millivolts, occurring at the ends of the linear voltage response to core piece position variations, represented respectively by the extremes of the pressure range. As shown in Fig. 9, when corrected by the null voltage-reducing circuit in question, null voltage varied, again irregularly and asymmetrically, from a minimum of approximately seven-tenth millivolt, occurring at the neutral position to maxima of approximately one and four-tenths millivolts occurring at the respective ends of the range piece position variation. Thus a null voltage reduction of some eighty to eighty-five percent with a sensitivity loss of only five percent may be accomplished by employment of the invention herein disclosed.

It has been observed during the course of extensive experiments relative to null voltage in dual secondary transformers that loading the secondary system results in a reduction of null voltage, but such reduction is accompanied by a reduction in sensitivity to a degree not nearly offset by the null voltage reduction. It will be evident, therefore, that the resistance 56 of the potentiometer must be sufficiently great to avoid loading the secondary. Also loading of the secondary by the auxiliary primary circuit is to be avoided, by choosing resistor 58 of suitably high value. Potentiometer resistances of the order of thirty to forty-five kilohms have been found to be satisfactory for a transformer having the output voltage range mentioned above. It may be noted here that inductive energization of the auxiliary primary winding by inductive coupling with the primary winding is so negligible, as compared with its direct conductive energization by the circuit connected across the secondary system as to produce no appreciable effect on the secondary voltages.

From the foregoing the fundamental aspects and types of arrangement that may be made to practice the invention will be evident, and it will be understood that many variations may be made from the specific disclosures without departing from the invention as defined by the appended claims.

I claim:

1. In a variable transformer that includes a main primary winding, a pair of secondary windings, and a core piece of magnetically permeable material inductively coupling said windings and movable relative to them for varying the respective degrees of coupling between the respective secondary windings and the primary winding; corrective means comprising an auxiliary primary winding mounted on the core piece and movable with it, and circuit means for energizing said auxiliary primary winding with alternating current having a preselected out of phase relation with voltage induced in the secondary windings.

2. In a variable transformer that includes a main primary winding, a pair of secondary windings connected in series aiding relation, and a core piece of magnetically permeable material inductively coupling said windings and movable relative to them for varying the respective de-

grees of its couplings with the respective secondary windings, corrective means comprising an auxiliary primary winding mounted on said core piece for movement with it, and circuit means for energizing said auxiliary primary winding, said circuit means having an input connected across both said secondary windings, and including phase shifting means for displacing current energizing said auxiliary primary winding to a preselected degree relative to voltage across said secondary windings induced by current energizing said primary winding.

3. In a transformer that includes a main primary winding, a secondary system of multiple windings connected in series, and a core of magnetically permeable material coupling said windings; a corrective circuit including an auxiliary primary winding coupled with said secondary windings through said core, an input coupled with said secondary system for energization by current induced in the latter during energization of said main primary winding, and phase shifting means connected in said circuit for producing a preselected phase difference between current energizing said auxiliary winding and voltage across said secondary system induced by alternating current energizing said main primary winding.

4. A corrective arrangement for a variable transformer having a main primary winding, a pair of secondary windings connected in series, a core piece of magnetically permeable material coupling said secondary and primary windings and means for varying the respective degrees of coupling of the different secondary windings with the primary winding, said arrangement comprising a circuit having output means inductively coupled with the respective secondary windings, means for increasing and decreasing the coupling of said output means with the different secondary windings as the degrees of coupling of the same secondary windings with the main primary winding are increased and decreased, and means for energizing said output means with alternating current of frequency corresponding to that of voltage across said secondary system induced by alternating current energizing said primary winding and having a preselected phase difference from the latter voltage.

5. In a variable transformer that includes a main primary winding and a pair of secondary windings connected in series; an auxiliary primary winding, magnetically permeable core means coupling both said main and auxiliary primary windings with said secondary windings and said core means being movable relative to said secondary windings for varying the degrees of their respective couplings with both said primary windings, and circuit means arranged to energize said auxiliary primary winding with alternating current of frequency corresponding to that of voltage across said secondary windings and having a preselected degree of phase displacement from said voltage.

6. In a null circuit error signal bridge arrangement that includes a variable signal transformer having a main primary winding, dual secondary windings connected in series aiding relation and with a midtap connected between them, and a core piece of magnetically permeable material coupling said primary and secondary windings and movable relative to the latter; and a potentiometer having its resistance connected across said secondary windings, and a variable intermediate tap; an auxiliary primary winding in-

13

ductively coupled with said secondary windings by said core piece, and a circuit for energizing said auxiliary primary windings, said circuit having an input connected across said secondary windings and including phase-shifting means for displacing the phase of current energizing said auxiliary winding to a preselected degree relative to voltage across said secondary windings induced by current energizing said main primary winding.

5  
10

14

References Cited in the file of this patent  
UNITED STATES PATENTS

| Number    | Name            | Date           |
|-----------|-----------------|----------------|
| 2,053,077 | Harrison -----  | Sept. 1, 1936  |
| 2,322,498 | Zeitlin -----   | June 22, 1943  |
| 2,358,725 | Mauerer -----   | Sept. 19, 1944 |
| 2,439,891 | Hornfeck -----  | Apr. 20, 1948  |
| 2,455,672 | Greenough ----- | Dec. 7, 1948   |
| 2,483,090 | Fuller -----    | Sept. 27, 1949 |