

Sept. 18, 1951

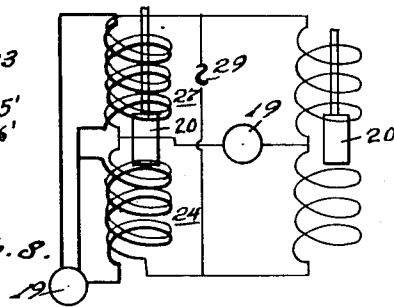
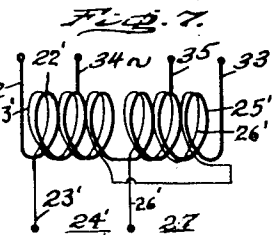
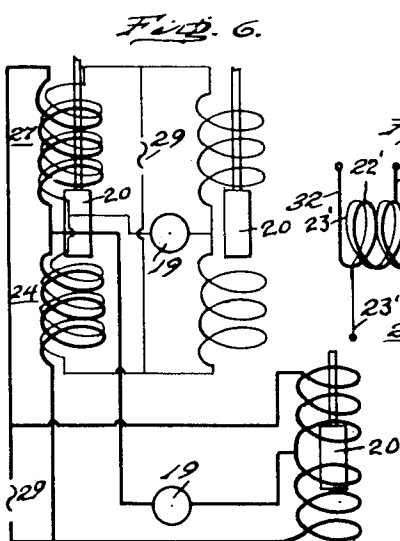
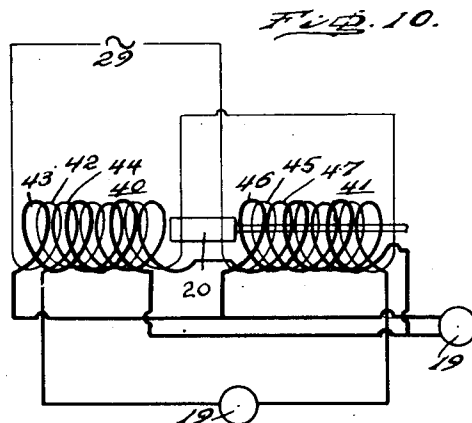
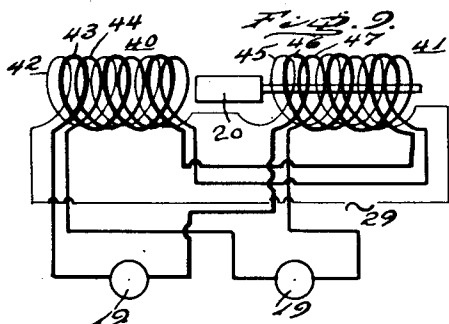
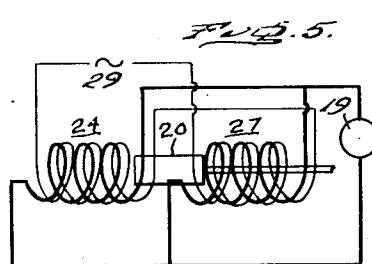
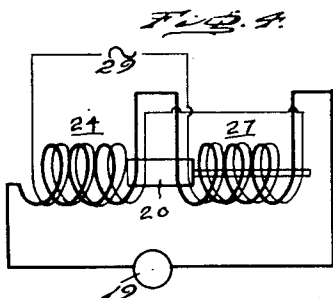
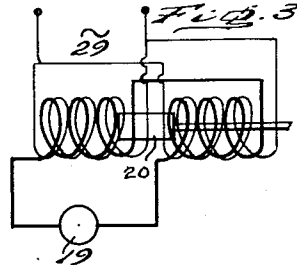
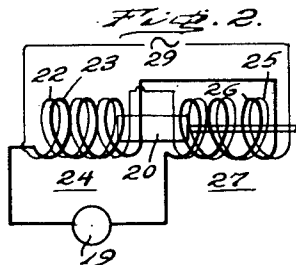
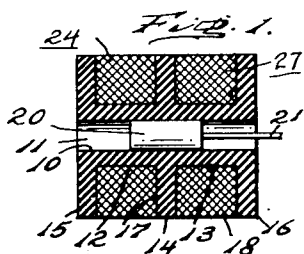
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2,568,587

DIFFERENTIAL TRANSFORMER

Filed Nov. 24, 1948

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

Fig. 3a.

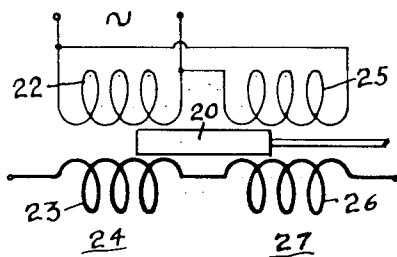


Fig. 5a.

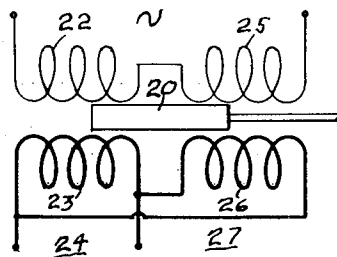


Fig. 11.

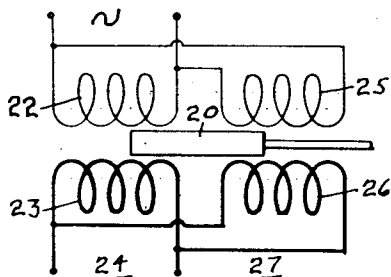


Fig. 12.

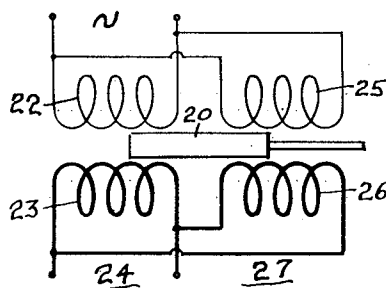
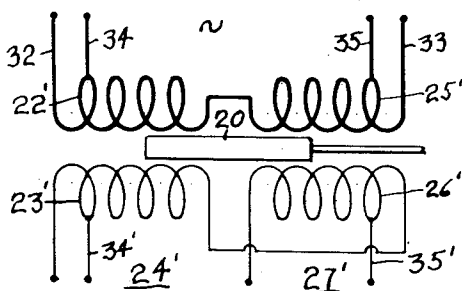


Fig. 7a.



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2,568,587

DIFFERENTIAL TRANSFORMER

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Application November 24, 1948, Serial No. 61,835

8 Claims. (Cl. 171-119)

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This invention relates to differential transformers.

Differential transformers have been used to a considerable degree for various control functions in various types of circuits, but so far as known each has comprised a single primary winding and a pair of secondary windings, or reversals of these elements in various arrangements thereof. An illustrative circuit and differential transformer assembly is shown, for instance, in my Patent No. 2,451,757. A specific differential transformer of the prior art type is also shown in my earlier Patent No. 2,427,866. In this latter patent three axially aligned coils are provided, of which the end coils are secondaries coupled in bucking opposition and disposed symmetrically on both sides of the central primary coil. An armature mass is mounted for axial relative adjustment on an axis concentric with the common axis of the three coils. When the primary is energized by A. C. the output of the coupled secondaries is a resultant of the combined theoretically cancelling outputs of the respective secondaries. Theoretically, with the armature in a centered position, the voltages induced in the respective secondaries is equal and of opposite and cancelling phases, so that the resultant output is null. As the armature and the aligned coils are relatively shifted in position in either direction from the null position, the voltage increases in one secondary and decreases in the other secondary, so that there is a resultant output of a phase of the preponderating voltage, and in amplitude a function of the movement away from the null position. Actual experience with differential transformers of this type indicates certain definite disadvantages and inaccuracies of this type of differential transformer, which militate against the accuracy and sensitivity thereof. For instance, the flux path of the transformer is relatively short with a consequent restriction on the length of the linear portion of the output curve thereof. The relative spacings between the secondaries and the primary is very critical, and even a minute difference between the two respective spaces changes the null output and may also give an output curve on the respective sides of the null position, which is asymmetrical relative to the null output. The windings have relatively high impedance with a poor capacity distribution so that even at the theoretical null position there is always a strong residual output, of the order perhaps of as much as a volt or even higher, from the secondaries depending

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upon the exciting frequency used. This is because the capacity effects prevent the full reversal of the phase of the respective voltages of the secondaries. Obviously this reduces the number of stages of amplification that can be associated with the transformer. A further disadvantageous function of such differential transformers develops when two or more are associated in a common circuit. In my circuit patent above mentioned, there is disclosed one three-coil differential transformer, the armature of which is moved in response to a change of condition, to furnish an output as a function of the displacement of the armature. The output is in a circuit with a motor and with a second differential transformer of the same type, the position of the armature of which latter is adjusted as a function of motor running, and when the output of the second transformer equals and cancels the output of the first transformer the motor circuit becomes null and the motor stops. Manufacturing tolerances for the formers upon which such three-coil transformers are wound are not small enough in practice to secure identical spacings between the primary and the secondaries, and even a minute difference between the coils shifts the null. When two transformers are associated in the same circuit, the traveling null, i. e. that point at which the circuit is balanced, whether at an actual supposed null relative position of the respective armatures in their transformers, or at any other relative position at which the outputs of the transformers are equal and cancelling, becomes by the inherent properties of the transformers indefinite and inaccurate. This causes errors to enter into the indications or controlling functions accomplished by the motor of the circuit, because the actual motor running to accomplish operative circuit null positions may be short, or, on the other hand, an overrunning of the true stoppage point. While in many installations these errors, which may be relatively small, may be permitted within the tolerances allowed, in many other installations where precision and exactness are prerequisites, the systems have not proven satisfactory. At best such transformers have required skill and time and additional items of equipment in endeavoring to balance or compensate for the errors in the instant transformers.

Finally the differential transformers of the prior art have been of fixed and inflexible characteristics having one invariable turn ratio of primary turns to secondary turns, incapable of variations or predeterminations to accord with

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the requirements of specific installations, and additionally have been of considerable size and of appreciable cost.

It is among the objects of this invention to provide a differential transformer which obviates the disadvantages of the prior art; to provide a differential transformer which is smaller and more compact, and is also cheaper and far more accurate than has heretofore been attained; to provide a differential transformer which incorporates both the actuating or exciting primary and the two coupled or couplable secondaries in an entity for the axial reception and movement of an armature, while being only of two-coil length; to provide a differential transformer which incorporates tap-off leads whereby free and easy change of response is preselected, to vary the output as a predetermined variable function of armature motion; to provide improved circuits incorporating the improved transformer whereby selective results can be attained which were previously not readily attainable by the prior art differential transformers; to provide coils for differential transformers arranged for interconnection in a complete differential transformer of predetermined but selectively variable characteristics; to provide a differential transformer of predetermined selected ratios of output voltages to input voltages; to provide differential transformers of two identical double wire coils having end connections and arranged for inter-connection so that selectively the primaries can be coupled in parallelism or in series bucking or aiding relation and in which the secondaries can be selectively coupled in parallelism, or in series aiding or bucking relation to provide selected characteristics of the complete transformer; to improve inductance bridges; to combine an inductance bridge with a differential transformer to effect improved circuit control systems; to provide primary and secondary windings as simultaneously formed turns in adjacency in two spaced but contiguous coil units so as to effect exact output and exciting coil arrangements to insure exact matching of related coils; to effect improvements in the details of differential transformers; to provide a differential transformer of relatively low impedance; to provide a differential transformer of even capacity distribution; to provide a differential transformer with an elongated flux path; to provide a two-coil differential transformer with the primaries coextensive with the secondaries in both respective coils as to secure such evenly distributed capacity that the null output when armature is properly associated therewith is of such small amplitude as compared with prior art three-coil transformers as to be susceptible to appreciably greater amplification than such three-coil transformers; to provide a differential transformer as two composite coils each comprising identical parallel turns of primary and secondary windings, with the coils in axial alignment with the coils spaced at an optimum but not critical spacing, wherein the inductive and capacitive effects of the respective coils are identical and evenly dispersed throughout both coils; to improve circuits containing differential transformers; and to provide other objects and advantages as will become more apparent as the description proceeds.

In the accompanying drawings forming part of this invention:

Fig. 1 represents a longitudinal diametric section through the complete transformer according to this invention, without the wiring connections

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thereof being disclosed in detail, and showing the relatively movable armature in its concentric axially movable position therein, and each coil of the transformer being comprised of plural adjacent turns of separate wires so that the primary and secondary of each coil of the two aligned coils are in adjacency throughout the turns of each coil.

Figs. 2 to 12 represent diagrams of the wiring of the transformer in various illustrative coupling and circuit arrangements.

Referring to Fig. 1, the transformer of this invention is shown as comprising illustratively a cylindrical former element 10, having the axial bore 11 extending for the full length thereof, and having an outer winding surface formed as two aligned surfaces respectively 12 and 13, separated from each other by the median division or radial wall 14, and terminating respectively in end walls or radial annular divisions 15 and 16. The hollow winding former element thus described is formed of suitable non-inductive material such as a ceramic or phenolic condensation product or the like. It will be observed that the external surfaces of the former provide respectively a winding space 17, defined by walls 14 and 15 and peripheral surface 12, and a winding space 18 defined by the walls 14 and 16 and peripheral surface 13. The axial bore 11 is of such size as to accommodate and permit relative axial motion of an armature mass 20, under the actuation of a control link or extension 21 generally aligned with the bore.

In the simplest form of the invention and as shown in Figs. 2, 3, 4, 5, 6, and 8, a primary winding 22, indicated in light lines, comprising a first wire, and a secondary winding 23, indicated by the heavier lines comprising a second wire respectively in said diagrams as one composite coil 24 of the transformer, and a primary winding 25 indicated by dotted lines comprising a third wire, and a secondary winding 26 indicated by the full lines in said diagrams, comprising a fourth wire, as the other composite coil 27, are provided. The coils 24 and 27 are wound as follows: Wires 22 and 23 are laid together at one end of the space 17, and wires 25 and 26 are laid together at one end of the space 18, with predetermined lengths of ends thereof extending generally radially or axially of the former for ultimate interconnection with other ends to be described. Maintaining equal tensions on both wires of both coils, the former is then rotated and the pairs of wires are thus laid on and guided by complementally moving traversing guides or the like back and forth to effect a tight winding of both wires simultaneously in lateral and vertical adjacency for the desired number of turns and multiple layers of turns in both coils. Free ends of the last turns are exposed for ultimate interconnection according to the desired results, and the given transformer, basically has then been formed. It will be observed that there are exactly equal turns of both primaries and secondaries in both coils on the same diameters so that the initial inductive effects of both coils are identical and with the primary coextensive with the secondary in both coils the capacity is evenly distributed throughout each coil. The conclusion of the final winding step finds two relatively disconnected slightly spaced coil masses of generally cylindrical form in axial spacing but in axial alignment. The free ends of both coil masses may pass inwardly or outwardly of the former and of the coils, or the ends may pass axially through contiguous

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walls for ultimate interconnection as will be described. It will be clear that the former may comprise a removable arbor, and the walls may be replaced by air gaps, and the support of the coils may be by an external sleeve, or by a skeleton or tubular internal guide or they may be secured together merely by suitable adhesive, or molded together in a binder, if desired, without departing from the spirit of the invention.

The method of forming the transformer outlined above conduces to ready and facile changes in or preselection of the interconnection of the terminals of the coils for the attainment of predetermined characteristics of the ultimate transformer.

In producing desired differential transformers according to this invention, it is necessary that the respective four windings of the respective two composite coils be considered as two primaries and two secondaries, and desirable effects are attained whenever either the primaries or the secondaries are coupled in bucking relation. The bucking relation may be either as series bucking or parallel bucking, whether in the primary or the secondary. To illustrate some of the forms of interconnection the invention makes possible, a few of the circuits available have been disclosed in the diagrammatic figures. A source of A. C. as the means for energizing the primaries, as indicated at 29, and an instrument 19 is shown which is to be understood as either an instrument or the input to a further complete circuit modified or affected by the transformers shown. For simplicity in the diagrams, single turns are illustrated, but it will be understood that there are multiple layers of multiple turns in each composite coil.

In Fig. 2, the secondaries 23 and 26 are coupled in bucking series relation in a circuit containing the instrument 19, while the primaries 22 and 25 are in series aiding relation in series with the actuating voltage source 29. This establishes a turn ratio of primary turns to secondary turns of 1 to 1. This can be reversed, to establish the primaries in bucking series relation with the source of A. C., while the secondaries are in series aiding relation, as shown in Fig. 4, with, of course, the same turn ratio of one to one. In Fig. 3 the coupling is with the primaries in parallel and the secondaries in series bucking relation to establish a turn ratio of smaller than one to one. Obviously, the primaries could be in bucking parallel relation and the secondaries in series aiding relation to secure the same turn ratio, as shown with schematic separated windings for clarity in Fig. 3A. In Fig. 5 the primaries are in series bucking relation while the secondaries are in parallel to establish a turn ratio which is less than one to one. It will be obvious also in connection with Fig. 5 that the secondaries could be parallel bucking relation while the primaries could be in series aiding relation, to maintain the same turn ratio as in Fig. 5, namely greater than one to one, as shown with schematic separated windings for clarity in Fig. 5A. Other combinations will suggest themselves to those skilled in the art without departing from the spirit of the invention, so long as either the primaries or the secondaries are in bucking relation, whether series or parallel. In Fig. 11, the schematic separated windings are shown with the primaries coupled in parallel bucking arrangement, while the secondaries are coupled in parallel aiding arrangement, to furnish a turn ratio of 1:1. In Fig. 12, the schematic

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separated windings are shown with the primaries coupled in parallel aiding arrangement, while the secondaries are in parallel bucking arrangement also to furnish a turn ratio of 1:1. All of these combinations of windings are available from the basic four-wire two-coil assembly shown. The general rule in these various couplings is as follows: with the primaries in series and the secondaries in series, the ratio is 1:1; with the primaries in series and the secondaries in parallel, the ratio is less than 1:1; with the primaries in parallel and the secondaries in parallel, the ratio is 1:1; with the primaries in parallel and the secondaries in series, the ratio is more than 1:1. While the voltage ratio does not follow the turn ratio, it has a useable functional relation thereto, and is therefore of importance in preselecting the particular coupling to be effected in order to meet certain circuit requirements.

In the figures as so far described, it will be seen that with the primaries energized by the source of A. C., the armature mass 20, coupled, for instance, to the movable element of a condition-responsive element, such, for instance, as that which will respond to temperature, pressure, or the like, is arranged for axial shifting along the common axis of the two composite coils of the transformer. At some point at which the center of the mass is symmetrically between the two composite coils there will be developed a substantially null output from the secondaries, manifested as an indication in the instrument 19 or in the amplifying circuit with which it is associated. There will be at the null point a residual output of a small voltage of the order of one or more millivolts, but this is relatively inconsequential and if the instrument 19 is replaced by connections as the input of a control circuit, any desired degree of amplification can be used with safety and propriety so as to secure the desired control results. This negligible residual voltage is in marked contrast to the residual voltage of the three aligned coils of the prior art, in which, in the average construction, the residual output is of the order of one or more volts, which obviously affects the number of stages of amplification that can be used in the circuit. Movement of the armature in either direction induces a resultant output which increases from null as a linear function of armature movement with the length of the linear portion of the curve appreciably longer than is possible of the three-coil transformer of the prior art. By the transformer of this invention the length of the flux path of the transformer is increased, the spacing between coils is not critical, and the linear portion of the output curve of the transformer is greatly lengthened as compared to the prior art three-coil assemblies. There is an optimum spacing of the order of one-quarter inch between the composite coils of the instant invention, but this is not critical, as slight deviations either way may occur without appreciable change in efficiency.

Fig. 6 illustrates the usefulness of the invention as applied to an inductance bridge. In this case a dual transmitter is secured feeding two measuring circuits. In this case it will be clear that more windings than the two described could be used in connection with both coils, as will be more fully developed in connection with the description of Figs. 9 and 10.

Fig. 8 illustrates an inductance bridge and differential transformer combination. In this

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case the primary circuit comprising the primaries of the two coils of the transformer unit become the inductance bridge transmitter, while the secondaries become the differential transformer transmitter.

In Fig. 7 a modification of the transformer of the earlier figures is disclosed in which while the primary and secondary first and second wires respectively 22' and 23' of coil 24; and the third and fourth wires respectively 25' and 26' of coil 27, are wound simultaneously and in equal lengths, during the winding a loop is made in the primaries at the same point respectively on the wound coils, which are brought radially or axially out of the composite coil and former to form taps, which, being identical in each of the related coils, maintains the balance. In this case, the primary is illustrated in heavy lines, and the secondaries are in light lines. This furnishes external connectors 32 and 33 for the full use of the total primary wires 22' and 25' in the complete coil, and internal connectors 34 and 35 for an abbreviated total primary coil, and with the secondaries coupled in bucking opposition for instance it will be seen that the ratio of armature movement to change in the secondary circuit will be predeterminedly greater when the primary is fed through the internal connectors 34 and 35, than when it is fed through the external connectors 32 and 33. By proportioning the turns predetermined changes can be secured in the output of the secondaries. It will be understood that suitable switching devices (not shown) may be used to secure changes in the primary coupling to the power source, and thus changes in the proportionate output determined by the armature movement. This is of value in relatively expanding a reading of a condition change in the critical range of the condition. It will be seen that if the input of the primary is changed from the external taps or connectors to the internal taps or connectors the output of the secondaries will drop by a given amount. Also, it will be clear that the transmitter coil will receive more energy in the primary, since the ZI^2 drop from 34 to 35 is less than that from 32 to 33, and its output will increase. The net result for a two-coil null balance system is a definite increase in receiver motion (relative armature motion for balance) for an equivalent motion.

It will be further understood that within the purview of the invention it is not necessary that the number of windings or of the separate wires used in a compound or composite winding be restricted to the two already described, as the invention has utility when three or even more windings are simultaneously applied to make up the complete composite coil. Referring to Fig. 9 and Fig. 10, two complementary co-axial coils 40 and 41 are shown and each is comprised of three wires laid on simultaneously. Thus, respectively, there would, in coil 40, be a primary 42 shown in lightest lines, a first secondary 43 shown in heaviest lines in Fig. 9, although for clarity it is shown in intermediately heavy line in Fig. 9, and for clarity in Fig. 10 in the heaviest lines, and a second secondary 44 shown in full lines. Coil 41 comprises the primary 45, shown in dotted lines, the first secondary 46, shown in a dot and dash line, and the second secondary 47 shown in full lines. This device connected as a differential transformer with a turn ratio of 1:1 and with two secondaries, is particularly useful as a device for running two or more instruments or

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controlling two or more circuits from one transmitter. In the connections shown, the primaries are in series aiding relation and the secondaries are respectively coupled in series bucking relation. It will be clear that more than three wires can be incorporated to good advantage in a given composite coil if for any reason this should be preferred.

In Fig. 10, the same multi-wire coils 40 and 41 are disposed in an alternative coupling arrangement. In this figure the primaries are disposed in series bucking arrangement, the first secondaries are coupled in parallel relation, so that the turn ratio is 1:1, and the second secondaries are in series aiding relation to establish a turn ratio of 1:1.

It will be understood that an increasing number of coil combinations can be secured with more windings.

It will further be understood that the same tap connections can be provided for the secondaries as are shown in Fig. 7 for the primaries, and either in alternation with or in addition to the primary taps as shown with schematically separated windings for clarity, in Fig. 7A, with the secondaries provided with the tap internal connections 34' and 35'. Use of the latter proportionately decreases the armature motion. By such alternative tap use it will be seen that the desired ratio of output to armature motion can be proportionately increased or decreased.

The accuracy, efficiency and low production and operating cost of the transformers will be appreciated.

Matter disclosed but not claimed herein is being claimed in application Serial No. 244,484 filed August 31, 1951.

Having thus described my invention, I claim:

1. A differential transformer comprising a first and a second air-cored coil in axial alignment and juxtaposed relation in a non-magnetic assembly, the first coil being formed of at least a first and second wire, and the second coil being formed of at least a third and fourth wire, of which said first and third are identical and said second and fourth are identical, the respective coils each comprising identical multiple turns of their respective wires laid on in adjacency so that the coils are identical with said first and second wires, and said third and fourth wires respectively in mutual inductive relation throughout the lengths of their said respective coils, means interconnecting said first and third wires to form a transformer primary having connections for an energizing A. C. input, means interconnecting said second and fourth wires to form a transformer secondary having output connections and connectively isolated from the transformer primary, and a magnetic core disposed for axial adjustment in and relative to the two aligned coils, the said interconnections establishing the output of the transformer secondary as a resultant of opposing voltages whereby with the core substantially medially disposed in the coils the secondary output is substantially null becoming a voltage of one phase or the opposing phase as the core relatively moves from the medial disposition in one direction or the other increasing in amplitude as a linear function of movement from the medial position, said linear change in amplitude being symmetrical on both sides of said substantially null output.

2. A differential transformer as recited in claim 1 in which said first and third wires are

in series relation, said second and fourth wires are in series relation, one of said series relations establishing bucking relation between the interconnected wires to establish a 1:1 turn ratio of primary to secondary in the differential transformer.

3. A differential transformer as recited in claim 1 in which said first and third wires are in series aiding relation, said second and fourth wires are in series bucking relation to establish a 1:1 turn ratio of primary to secondary in the differential transformer.

4. A differential transformer as recited in claim 1 in which said first and third wires are in parallel relation and said second and fourth wires are in parallel relation, one of said parallel relations being a bucking relation to establish a predetermined turn ratio of primary to secondary in the differential transformer of 1:1.

5. A differential transformer as recited in claim 1 in which the wires comprising the transformer primary are connected in parallel relation and the wires comprising the transformer secondary are connected in series bucking relation to establish a turn ratio of primary to secondary of greater than 1:1.

6. A differential transformer as recited in claim 1 in which the transformer primary and the transformer secondary respectively comprise stator members, the wires of at least one stator member being looped intermediate the free end thereof to constitute tap connections in said member for varying the ratio of output of the transformer.

7. A differential transformer as recited in claim 1 in which said first coil is formed with at least a fifth wire in addition to the said first and

second wires, and the said second coil is formed of at least a sixth wire in addition to said third and fourth wires, which fifth and sixth wires are identical, means interconnecting said fifth and sixth wires to form an additional transformer secondary having output connections and connectively isolated from both the transformer primary and the said first transformer secondary.

8. A differential transformer as recited in claim 1, in which the transformer primary and transformer secondary comprise stator members, one of said members having its wires in series relation and the other member having its wires connected in parallel relation, one of said relations being bucking, to establish a predetermined turn ratio of primary to secondary in the differential transformer of other than 1:1.

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