Sept. 18, 1951 W. D. MACGEORGE 2,568,588

DIFFERENTIAL TRANSFORMER WITH LONG STROKE AND LINEAR OUTPUT

Filed June 7, 1950

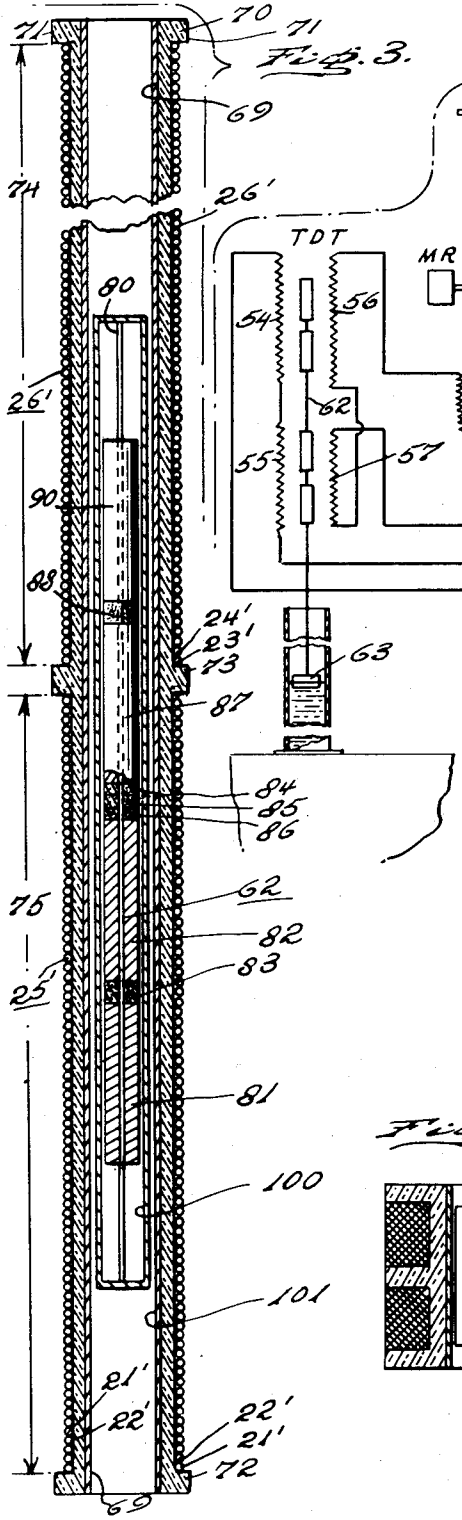


Fig. 3.

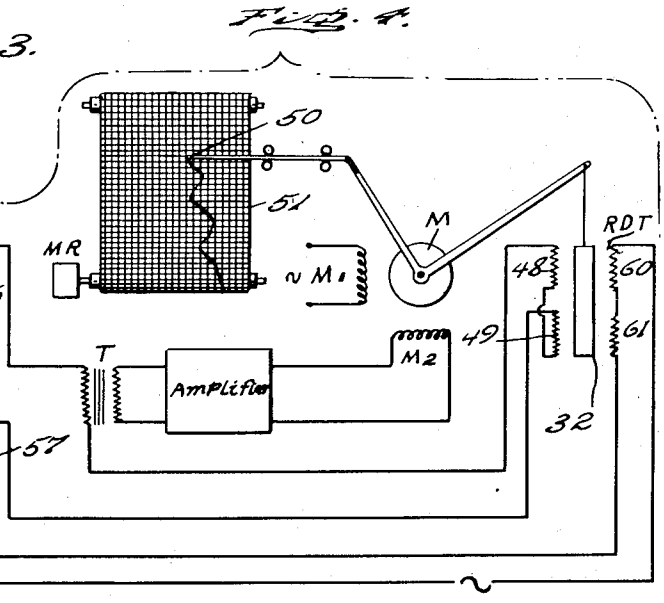


Fig. 4.

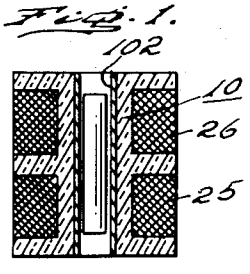


Fig. 1.

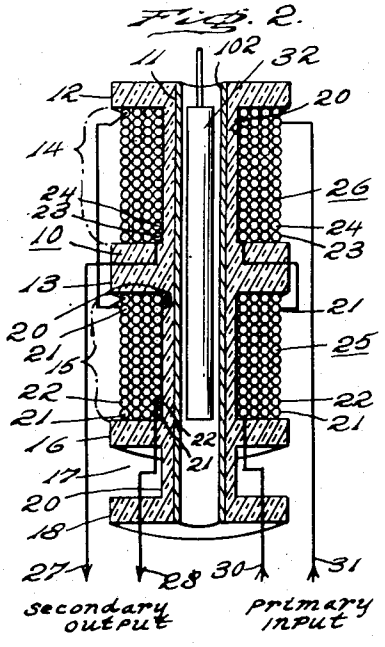


Fig. 2.

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DIFFERENTIAL TRANSFORMER WITH LONG STROKE AND LINEAR OUTPUT

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11 Claims. (Cl. 171—119)

1

This invention relates to differential transformers of the relatively movable armature type.

In application Serial Number 61,835, filed November 24, 1948, I disclosed a novel improved differential transformer possessed of many important advantages over all known prior art, of which many have been successfully installed. One illustrative typical use of said differential transformer is in connection with a system incorporating two or more identical differential transformers, of which one is a transmitter, the relative position of the armature of which is determined by a prime mover, responsive to changes in condition of a variable with which it is associated. The output of the secondaries of the transmitter-transformer is disposed in operative relation, usually in series, with the output of a receiver-differential transformer identical with the first, the position of the armature of which latter transformer is controlled by a servo mechanism such as an electric motor, in association with an interposed amplifier unit responsive to the resultant phase and voltage amplitude of the secondaries circuit. With the outputs of the secondaries of the two transformers in balance, everything is at rest. With a change in condition of the variable, the armature of the transmitter transformer is moved to furnish a transformer-secondaries unbalancing output which, through the amplifier, energizes the servo, the running of which actuates an indicator, recorder, or the like, or opens a valve, or performs any other necessary or desirable work, while simultaneously moving the armature of the receiver transformer to change the output of its secondaries. The armature motion with the running of the servo continues until the output of the receiver transformer becomes such as to re-establish balance in the secondaries circuit, at which point the servo stops, and the associated indicator, strip chart recorder or the like indicates by its changed indication the change in the condition of the variable to which the transmitter is responsive. This system is generally as disclosed in Hornfeck Patent No. 2,420,539.

A feature of the differential transformer disclosed in said application and as commercially developed thereunder is the fact that the output of the secondaries is linear, that is, the amplitude increases or decreases proportionally to the movement of the armature from or relative to the position of substantially null output or from a given output by a further relative movement of the armature, with a phase determined by the sense of the movement from the null output position of the particular transformer. Furthermore, with applicant's said novel transformer this linear output is always symmetrical about the null output position. As a further important advantage of applicant's said transformer, there is the fact that the armature movement, either in unbalance from the transmitter or in rebalance from the receiver, can develop a useable signal with motions of the armature as small as .00004". This presents constituents or components of an extremely sensitive and accurate system, which has had excellent commercial acceptance. A transformer as described, having a linear response to extremely minute armature relative movements, is referred to hereinafter as a "standard" transformer.

2

The improved novel standard differential transformer as set forth in said application replaces the previously well accepted three coil differential transformer, namely an air cored hollow stator formed of a central hollow air cored primary coil, with which two secondary hollow coils were associated on opposite ends of the primary coil in end to end air spaced relation to the respective ends of the primary coil and coupled in series bucking relation, as shown in applicant's earlier United States Patent No. 2,427,866.

An important structural feature of applicant's said improved transformer of said pending application lies in the fact that it comprises two identical aligned hollow air cored air spaced coils, each coil formed of identical turns of a plurality of wires, laid on in adjacency, of which one wire is a primary and another wire is a secondary in each coil, and with the respective primary wires being identical, and the respective secondary wires being identical, and coupled and interconnected so as to furnish a bucking output from the respective terminals of the secondaries. With this novel improved coil arrangement of the standard transformer, not only is the flux path longer than in any prior transformers, so that the linear output curve is appreciably longer, but also the air spacing between the two coils is not critical. In contrast to this, the air spacing between the primary and the respective secondaries of the former three coil type is critical, and if not identically the same lends asymmetry to the curves of the output. Moreover, the residual voltage at the null output relation of the stator and armature of the three coil system is always high, of the order of a volt or higher, whereas with applicant's standard transformer the residual voltage at the null output relation of stator and armature is of the order of perhaps one millivolt, due,

among other factors, to the low impedance and excellent capacity distribution thereof as compared to the three coil transformer disclosed in said patent, or any other known differential transformer.

Owing to the success of applicant's standard transformer arrangement there is, as noted, a rapidly growing number of installations of the transformer systems as above discussed, and the structure of the servo motor, the amplifier and the standard receiver transformer, utilizing applicant's transformer construction has attained substantially a production line of commercial developments. Thus, receiver units are in production comprising a strip chart or other recorder, a servo for actuating the recorder, an amplifier and a receiver standard differential transformer actuated by the servo. These are designed for operative assembly with transmitter units which differ as to the particular prime mover used, according to the nature of the particular variable to be measured or controlled, but each incorporating a standard differential transformer identical with that of the receiver.

The prime movers of the transmitters may be Bourdon tubes, bellows, thermostats, levers, or any other general or special prime mover. Whatever the prime mover, owing to the identity of the transformers according to the said application, they are arranged for incorporation in the system formed by assembly with the amplifier, servo mechanism, recorder, and standard receiver transformer. The motion of the servo has been "geared" down effectively to produce the slight armature motion required in a substantially lagless drive thereof, and the prime mover motion has been similarly translated into related slight armature movements in the transmitter.

However, efficient and important as these developments have been, they have heretofore been restricted in the transmitters either to prime movers having extremely slight movements, or, with devices having larger movements, to small portions of the wider movements or paths of movements, or to the use of some motion reduction systems which are both expensive and inefficient and often impart non-linear effects. So far as known, in the case of flow meters, liquid level indicators, or, in fact any devices having strokes or movements in response to the energizing changes of conditions which are of considerable magnitude, there has not previously been available in the art any transmitting device which could give a linearly developed signal as a function of such exaggerated stroke along a long path capable of "matching" the output of any transformer having a minute armature movement, and especially none that could furnish a linear output operable in the assembly of amplifier, servo mechanism and rebalancing transformer with its linear output as outlined above.

It is among the objects of this invention to provide a movable element differential transformer of the null balance type having a very elongated movement of the movable element with a symmetrical linear output proportional in amplitude to the relative motion of the armature from or relative to the null output relation; to provide a differential transformer with a movable element armature operable by movable elements of long strokes to provide a linear output; to provide a balancing system including an amplifier, a servo mechanism, and a differential transformer, with the latter having an output which is linear from the null output position with

very minute armature movements, and with which is associated a transmitter differential transformer having a linear output from a null output position with exaggeratedly long armature movements so that the linear curves match with widely different armature movements; to provide a pair of differential transformers having the same electrical characteristics, but of which one has an output increasing from a null output position as a function of a minute armature movement while the other has an output increasing from a null output position as a function of a large armature movement; to provide a first differential transformer constructed according to the teachings of said application with each coil formed of multiple turns of at least two wires of known resistances and disposed in a given axial length of coil, with which is associated an armature for axial sliding motion relative to the two coils, and a second differential transformer constructed according to the basic teachings of said application with each coil formed of multiple turns of at least two wires of known resistances and disposed in a given axial length of coil appreciably longer than the axial lengths of the coils of the first transformer with the number of turns and the total resistance of the wires correlated to furnish a linear output in response to a longer movement of an associated armature, with which is associated a modified armature for axial sliding motion relative to said coils; to provide a first differential transformer formed of two coils of multiple turns of at least two wires of given axial length and known total resistance having a linear curve of voltage output resulting from a minute armature movement, and a second differential transformer formed of two coils of multiple turns of at least two wires of a greater axial coil length and substantially identical total resistance to that of the first transformer, having a linear curve of voltage output resulting from a highly magnified movement of an armature, which respective curves substantially coincide; to provide two matching differential transformers each having a linear curve of output with relative motions of associated armatures, of which one has a predeterminedly greater stroke than the other in producing such linear curve of output; to provide a pair of matching differential transformers, each being formed of two air cored coils formed of two wires laid on in adjacency to form identical numbers of turns of similar wires, of which one is of appreciably shorter axial length than the other, whereby linear outputs are produced by relative movements of respective coaxial armatures with widely divergent strokes; to provide two differential transformers having relatively movable armatures of widely different respective armature strokes, but with substantially identical impedances; and to provide other advantages as will become apparent as the description proceeds.

In the accompanying drawing forming part of this description:

Fig. 1 represents a longitudinal diametric section through the complete transformer according to the invention of said application, each coil of which is formed of multiple adjacent turns of separate wires, but without wiring connections.

Fig. 2 represents a schematic section through the transformer according to the teachings of said application showing illustrative wiring connections therefor, and the individual wires of the multiple turns, with the wires of exaggerated

size and showing a restricted number of layers of the turns as compared with the average "standard" transformer, for illustrative clarity.

Fig. 3 represents a schematic section through the axially elongated transformer of this invention, showing a modified type of armature by which the desired linear response can be obtained.

Fig. 4 represents a schematic wiring diagram of an illustrative circuit incorporating a transmitter differential transformer according to the disclosure of Fig. 3, and a standard receiver differential transformer according to the disclosure of Fig. 2, for attaining null balance of the circuit for stopping the servomotor and moving an associated device to a related position, illustratively a strip chart recorder.

Referring to the disclosure of Fig. 2, a purely illustrative embodiment of the standard transformer according to the said application is provided. This comprises a ceramic or like former or spool 10, comprising a cylinder having an axial bore 11, and a plurality of peripheral flanges, comprised of end flange 12, defining one end of one coil space 14, median, preferably slightly larger, flange 13 defining on one surface the other end of the coil space 14 and on its other surface defining an end of the other coil space 15 of the transformer. The last mentioned coil space is defined on its other end by a peripheral flange 16. A coil-tying and terminal connector space 17 is defined at the end of the former or spool 10 by the said flange 16 and a terminal flange 18. The depth of the coil space is established by the outer diameter of the tube 10 by cylindrical surfaces 20

In winding the transformer in the illustrative case under discussion, two wires are laid on at one end of space 17, respectively 21 and 22, in side by side adjacency, starting, for instance, adjacent to the flange 16. Another pair of wires 23 and 24 are laid on at one end of space 14, say, adjacent to the flange 13. As by rotating the spool or former 10 the wires are wound and laid on in a multiplicity of turns, forward and back in a plurality of layers until enough turns and layers of turns have been laid on as may be desired for the particular desired result. To complete the transformer, interconnections and terminal leads are connected so that, for instance, the wire 21 of completed coil 25 is connected in series with wire 23 of completed coil 26, to form the primary winding for the transformer, and wire 22 of coil 25 at its end adjacent to the flange 13 is connected to the wire 24 of coil 26 at its end adjacent to the flange 12, to couple the secondary windings in series bucking relation, having output leads 27 and 28. The primary input connections 30 and 31 are connected to the respective ends of the series-connected primary windings. To complete the transformer an armature mass of magnetizable material as indicated at 32 is mounted for axial sliding in the bore 11. This is preferably of the same axial length as the total combined lengths of the coils 25 and 26, plus the spacing flange 13.

The illustrative standard transformer as thus described when energized by A. C. in the exciting coil has a linear curve of voltage output, which is symmetrical about the null output position of the armature relative to the stator. The increments of armature movement to secure the linear output and a useable signal on this curve are quite minute and with suitable amplification and a proper servomotor have been as small as .00004".

Before describing the transformer according to its embodiment in this invention, an illustrative complete null balance system as has heretofore been used with the standard transformers will be described, modified in part by the presence therein of the novel transformer of this invention, to be described. In the circuit it will be understood that range changes will or can be incorporated as in the standard circuits used in the systems, using either an additional fixed transformer with a differential between the windings of two secondaries, or shunting out some of the turns of one of the standard differential transformers, but which need not be described at this point. In the purely illustrative circuit of Fig. 4, the motor M has one field M_1 constantly energized by a suitable source of A. C., while the other power field M_2 is selectively energized by the output of the amplifier, either of substantially no voltage, or of a voltage of A phase or B phase, each substantially 90° out of phase with the phase of voltage energizing the field M_1, respectively in one angular direction or the other relative to the phase of the voltage in M_1, so that the motor M runs selectively in one direction or another, or stops, as will be clear. The servomotor M, in its running, actuates any suitable element of a recorder, such as the scribing point 50, operative transversely relative to a strip chart 51, moved at a timed rate by a second motor MR.

A receiver differential transformer R. D. T. is provided which is usually the said standard transformer, having primaries 60 and 61 and secondaries 48 and 49, with mutual interconnections so that the outputs of the secondaries are respectively mutually bucking, as taught in said copending application. For simplicity, but not necessarily, the primaries are shown as series-aiding relation, and the secondaries are shown as series bucking relation. The output of the secondaries is controlled by the positioning of the armature 32 which is axially movable and positionable in the stator formed of the said primary and secondary coils, by a suitable link or like connection to the motor M. As the motor M runs in one direction or the other predetermined increments of armature position change attach to the armature for a given predetermined number of rotations of the motor M.

A transmitter differential transformer T. D. T. is provided, which may be and in the prior art is a "standard" differential transformer, but which in the present instance comprises the improved impedance matching transformer of this invention, to be described. The transmitter transformer stator comprises primaries 54 and 55, and secondaries 56 and 57, and each having mutual interconnections so that the outputs of the secondaries are mutually bucking, as taught in said co-pending application. For simplicity, the primaries 54 and 55 are shown in series aiding relation and the secondaries are in series bucking relation.

The primaries of the transformers R. D. T. and T. D. T. are in series with each other and with a suitable source of A. C. or with suitably differentially wound secondaries of a fixed transformer, if a range change is to be incorporated in the system. The outputs of the secondaries of the transformers T. D. T. and R. D. T. are series connected through the primary of a fixed transformer T, the secondary of which feeds an am-

plifier, and which in turn controls the voltage impressed upon the power winding M_2 of the motor M. The output of the transformer T. D. T. is controlled by a long stroke armature 62, to be described, the prime mover for which is a device having a long range of movements, such as a float in a rotometer or a liquid level indicator or the like, indicated generally at 63.

With everything in balance, the scriber 50 is at a given position relative to the strip chart 51, coinciding with a given position of armature 62 of the transmitter T. D. T. as a function of the condition of the variable, and the motor M is stationary. With movement of the armature 62 of the transmitter transformer T. D. T. the output of the secondaries 56 and 57 changes and unbalances the outputs of the secondaries 60 and 61 of the receiver transformer R. D. T., which, through transformer T and the amplifier places a voltage of given phase on the power winding M_2 of the motor M, and the motor runs in the proper direction and to a degree such that the armature 32 is repositioned in the transformer R. D. T. to change the outputs of its secondaries 60 and 61 until it re-establishes balance with the previously changed output of the secondaries of transformer T. D. T., until the outputs of the secondaries are again in balance, when the motor stops. Meanwhile, the scriber 50 has moved relative to the chart 51 until the change of its setting corresponds with the change in the prime mover 63 which actuated the armature 62 of the transformer T. D. T. With "standard" differential transformers having complete electrical identity, the linear output of both transformers conduces toward extremely accurate balance and accurate measurements and recordations of the disturbance or temporary unbalance.

In order to furnish an illustration of the dimensions and proportions of the standard differential transformer, in a purely illustrative embodiment thereof, as a background for the improved transformer of this invention, let it be assumed that the coils of the standard transformer are each formed of two wires laid on in adjacency in multiple layers, that there are 400 turns of each wire in each coil, that the finished coils are ⅛ of an inch in thickness with an internal diameter of ½ inch, and that each coil is ⅝ of an inch long, the illustrative wire used is enameled wire of .0088" in diameter, and the resistance of the respective wires measured over the 400 turns is known. To form a matching elongated transformer having a long stroke for an identical output curve, in an illustrative case, an elongated hollow spool of ceramic or like dielectric material is formed, the outer circumference of which is of the same diameter as the average diameter of the "standard" coil mentioned. With a standard coil radial thickness of ⅛ of an inch, and an internal diameter of the standard coil of one half of an inch, the average diameter of the standard coil is ⅝ of an inch and this is preferably selected as the diameter of the spool. The spool 70 having an internal bore 69 with an external diameter then of ⅝ of an inch, is formed with shallow end flanges 71 and 72, each spaced from a wider central shallow flange 73, by an illustrative seven inches of coil area, respectively 74 and 75, so that the operating length of the elongated transformer of this invention is 14 inches plus the width of the central flange area, which is of the order of 1 and ⅛ inches. Upon the same ends of the respective coil areas, for instance, at the left hand thereof adjacent to the respective flanges bounding those ends of the areas 74 and 75, two wires, respectively 21' and 22', and 23' and 24', illustratively, preferably identical respectively with wires 21, 22, 23, and 24, are laid on in adjacency, and the spool is turned to dispose the wires in elongatetd coil form filling the coil area spaces 74 and 75 with respective coils 25' and 26', but, of course, in a sharply reduced number of layers of turns, which in the illustrative case is formed of a single layer, of closely contiguous turns of the respective wires. The respective wires of the primary and secondary windings are interconnected as in the case of the standard transformer with which they are to be associated so that the secondary leads have bucking outputs. Owing to the elongated nature of the novel transformer as thus constructed, a modified form of axially mounted and movable armature 62 is provided. This provides the structure of transmitter transformer T. D. T.

In the illustrative case, the modified armature 62 comprises four armatures of the same general formation and size as the armature 32 of the receiver transformer R. D. T. To secure the proper alignment of the components of the armature, an aluminum or other rod or stiff wire of non-magnetic properties 80 is provided upon which armature components 81 and 82 are strung and fastened separated by a non-magnetic spacing washer or the like 83, of illustratively $\frac{3}{16}$ of an inch axial length with armature 83 spaced by three of such spacing washers 84, 85, and 86, from the adjacent end of an armature component 87, spaced by a single washer 88 from the terminal armature component 90. While with suitable care a single elongated integral armature may be constructed, it is found that the elongated compound armature gives efficient and satisfactory results, while simplifying the construction by providing simple multiples of the same armatures as are used with the said standard transformers.

While the improved elongated transformer as thus described is adequate to furnish a five inch stroke of the armature 62 in providing the linear matching output of the small standard transformer as described, it will be understood that in translating the turns of the standard transformer into the elongated transformer, it happens with the particular gauge of wire referred to, to dispose all of the turns in side by side laterally contacting relation in a single layer. If greater elongation of transformer and the stroke of the armature is required, the turns of individual wires are laid on the elongated former respectively in slightly or greatly spaced relation so that there is no side by side contact of the adjacent wires. On the other hand, for a shorter armature stroke for the given output it will be seen that the turns can be applied in side by side adjacency in more than one layer in a shorter elongated spool area, still greater than the standard, and still furnish the linear output desired, so long as the impedances are substantially identical.

While in securing the desired result it is simpler and easier to use the same gauge of wire with the same resistances, in both the standard and the elongated armature, and to provide a slighly greater diameter of the external spool surface than is used on the standard transformer, neither of these factors is limiting, as the only essential is that the two transformers have identical or substantially identical impedances.

Thus, using the system of the transformer of said application it will be seen that it is not essential

that the number of turns of the respective wires on the related coils be similar. The wires may be of different diameters and therefore of different resistance, and the difference in respective resistances may be compensated by having a suitable differential between the number of turns on the respective coils of the respective matching transformers. The problem in matching the outputs of the transformers having small and large strokes respectively is the phase shift control which is accomplished by the presence of identical impedance in both transformers.

It is contemplated that the elongated transformer armature or core 62 may be associated with a tubular housing under pressure to comprise of itself a float. Thus, a cylindrical tube of non-magnetic material, such as of brass, non-magnetic stainless steel or the like, encloses the armature components and may be closed at both ends and filled with gas so as of itself to comprise a float, or it may be sealed and mounted on a float. In any case, it protects the armature components against liquids which might attack the magnetizable material of the components. Such a non-magnetic housing is shown at 100. In order to protect the stator mounting from such liquid, it may be found desirable to insert a sleeve 101 of similar non-magnetic material axially through and even beyond the ends of the spool 80. This furnishes in this instance two thin layers of non-magnetic material in juxtaposition inside of the bore 69 of the elongated stator. This effects a phase shifting of the output of the secondaries of the elongated transformer affecting its matching with the output of the standard transformer. It is part of this invention to correct for this phase shifting phenomena in the standard transformer R. D. T. by simply inserting a brass or like non-magnetic sleeve 102 into the bore of the stator, within which the armature 53 moves. This short tube of the length of transformer R. D. T. and of the same general thickness as the two elongated tubes 100 and 101 of T. D. T. or of either, if but one is used, corrects the phase shift and causes the outputs of the two transformers to be exact sensitive accurate duplicates of each other, but with the widely different lengths of armature strokes or movements.

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 a second wire, and the second coil being formed of at least a third and fourth wire, of which the 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 the 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 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, said core comprised of a plurality of substantially cylindrical individual core elements in axially aligned air spaced relation, and means mounting the core elements for movement as a unit axially of said axially aligned coils.

2. A differential transformer as recited in claim 1, in which both coils are elongated to an extent adequate to receive and substantially house the plurality of aligned core elements in the null output relation thereof to the coils, and in which the coils are formed of multiple turns in appreciably less than a multiplicity of layers in effecting such elongation.

3. A differential transformer as recited in claim 1, in which both coils are elongated to an extent adequate to receive and substantially house the plurality of aligned core elements in the null output relation thereof to the coils, and in which the coils are formed of multiple turns in a single layer in effecting such elongation.

4. 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 a second wire, and the second coil being formed of at least a third and a fourth wire, of which the 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 the 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 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 medical position, said linear change in amplitude being symmetrical on both sides of said substantially null output, said core comprised of a plurality of substantially cylindrical individual core elements in axially aligned air spaced relation, and means mounting the core elements for movement as a unit axially of said axially aligned coils said last means comprising an enclosing tube of non-magnetic metal.

5. A differential transformer system comprising first and second differential transformers, the said first transformer comprising two identical air cored coils in axial alignment and air spacing and each comprising at least two wires laid on in adjacency in a predetermined number of

turns in a predetermined axial length, means interconnecting selected wires of the coils to form a primary and a secondary, the output leads of which latter have respectively mutually bucking outputs, and an armature core in axially movable relation to both coils to furnish a substantially null output or an output of voltage of selected phase and linearly changing amplitude proportional to relative movements of the armature relative to its null output relative position with small increments of relative armature movements, said second transformer comprising two identical air cored coils in axial alignment and air spacing each comprised of at least two wires laid on in adjacency in substantially the same number of turns as and in an axial length appreciably greater than that of the coils of the said first transformer, means interconnecting selected wires of the coils of the second transformer to form a primary and a secondary the output leads of which latter have respectively mutually bucking outputs, and an armature core of appreciably greater length than the said armature core of said first transformer axially movable relative to both coils to furnish a substantially null output or an output of voltage of selected phase and linearly changing amplitude proportional to relative movements of the second armature from its substantially null output position with longer increments of relative motion, means in the system for moving the armature core of the first transformer through small motions to secure a linear change of output from its said secondary, and means in the system for moving the armature core of the second transformer through larger motions to secure a linear change of output from its secondary equivalent in amplitude to the change in secondary output of said first transformer with small motions.

6. A differential transformer system comprising a first and a second differential transformer, each transformer comprising respectively two identical air cored coils in axial alignment and air spacing and each comprising at least two wires laid on in adjacency in multiple turns in a given axial length, means interconnecting selected wires of the respective coils of the respective transformers to form a primary and a secondary the output leads of which latter have respectively mutually bucking outputs, an armature core in axially movable relation to both coils of the respective transformers to furnish a substantially null output or an output of voltage of selected phase and linearly changing amplitude proportional to relative movements of the respective armatures relative to its null output relative position in the coils of the respective transformers, both transformers having substantially identical impedance but the given axial lengths thereof being widely different in the said two transformers, so that matching linear outputs from the transformers follows from widely different increments of armature movement in the respective transformers and means in the system for securing differential relative motions of the respective armatures and the respective aligned coils to secure identical outputs from the respective secondaries of the respective transformers.

7. A differential transformer system comprising a first and a second differential transformer, each transformer comprising respectively two identical air cored coils in axial alignment and air spacing and each comprising at least two wires laid on in adjacency in multiple turns in a given axial length, means interconnecting selected wires of the respective coils of the respective transformers to form a primary and a secondary the output leads of which latter have respectively mutually bucking outputs, an armature core in axially movable relation to both coils of the respective transformers to furnish a substantially null output or an output of voltage of selected phase and linearly changing amplitude proportional to relative movements of the respective armatures relative to its null output relative position in the coils of the respective transformers, both transformers having substantially identical impedance but the given axial lengths thereof being widely different in the said two transformers, so that matching linear outputs from the transformers follows from widely different increments of armature movement in the respective transformers and means in the system for securing differential relative motions of the respective armatures and the respective aligned coils to secure identical outputs from the respective secondaries of the respective transformers, the armature associated with the coils of greater axial length having appreciably greater length axially than the armature of the other of said transformers.

8. A differential transformer system comprising a first and a second differential transformer, each transformer comprising respectively two identical air cored coils in axial alignment and air spacing and each comprising at least two wires laid on in adjacency in multiple turns in a given axial length, means interconnecting selected wires of the respective coils of the respective transformers to form a primary and a secondary the output leads of which latter have respectively mutually bucking outputs, an armature core in axially movable relation to both coils of the respective transformers to furnish a substantially null output or an output of voltage of selected phase and linearly changing amplitude proportional to relative movements of the respective armatures relative to its null output relative position in the coils of the respective transformers, both transformers having substantially identical impedance but the given axial lengths thereof being widely different in the said two transformers, so that matching linear outputs from the transformers follows from widely different increments of armature movement in the respective transformers, said system comprising circuit means combining the outputs of the respective transformers in a signal relationship, means for relatively moving the armature of the axially shorter transformer with short increments of movement, and means for moving the armature of the longer transformer with longer increments to produce balanced signal relationship.

9. A differential transformer system comprising a first and a second differential transformer, each transformer comprising two identical air cored coils in axial alignment and air spacing, and each comprising at least two wires laid on in adjacency and multiple turns in given respectively different axial lengths, means interconnecting selected wires of the respective coils of the respective transformers to form a primary and a secondary out of conductive interconnection, and the output leads of which secondaries have respectively mutually bucking outputs, armature cores of respectively different lengths disposed in axially movable relation to both coils of the respective transformers to furnish a substantially null output or an output of given phase and linearly changing amplitude proportional to relative movements of the respective armatures rela-

tive to its null output relative position in the coils of the respective transformers, the longer of the said armatures being mounted for motion in the transformer from the coils of greater axial length, the impedances of the respective transformers being substantially identical so that the linear outputs are of identical phase relations and arise from widely different axial movements of the respective armatures, with the longer armature having a longer stroke in its transformer for the linear output than the armature of the other of said transformers means in the system for relatively moving the armature of the axially shorter transformer through a relatively small motion to produce a change from null output to a linearly developed maximum amplitude of output, and means in the system for relatively moving the longer armature of the axially longer transformer through a relatively large motion to produce a change from null output to a linearly developed maximum amplitude of output the equivalent of the maximum output of said axially shorter transformer.

10. A differential transformer system comprising a first and a second differential transformer, each comprising two identical air cored coils in axial alignment and air spacing, the first coil being formed of at least a first and a second wire, and the second coil being formed of at least a third and a fourth wire, of which the first and third are identical in all coils, and of which the second and fourth are identical in all coils, the respective coils each comprising identical multiple turns of their respective wires laid on in adjacency so that the coils are electrically substantially 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, but with the coils of the first transformer in multiple layers in a given axial length with a given internal diameter and the coils of the second transformer in a fewer number of layers and in an appreciably greater axial length on a slightly greater internal diameter than the coils of the first transformer, means interconnecting said first and third wires of the respective transformers to form primaries having connections for an energizing A. C. input, means interconnecting said second and fourth wires of the respective transformers to form secondaries having output connections and connectively isolated from the primaries of the respective transformers, and first and second magnetic cores of appreciably different axial lengths disposed respectively for axial adjustment in and relative to the respective aligned coils of the first and second transformer, the said interconnections establishing the outputs of the secondaries of the respective transformers as a resultant of opposing voltages varying from a substantially null output to an output of one phase

or an opposing phase as the core moves relative to a position of substantially null output increasing in amplitude as a linear function of movement relative to said position of substantially null output, the increments of core movement for a given voltage output being widely different in the respective transformers, and means in the system for imparting the respective increments to the respective armatures of the respective transformers to furnish equivalent voltage outputs into the system from said respective transformers.

11. A differential transformer system comprising a first and a second differential transformer, one of which has a relatively small range of movement of the relatively movable element thereof for producing an output progressing in a substantially linear curve from a substantially null output to a signal of given amplitude, said other transformer having a relatively large range of movement of the relatively movable element thereof for producing an output progressing in a substantially linear curve from a substantially null output to a signal of the same said given amplitude, means coupling said transformers in a balancing network, a first actuating means having a relatively short stroke coupled to the relatively movable element of the transformer having the relatively short stroke, a second actuating means having a relatively long stroke coupled to the relatively movable element of the transformer having the relatively long stroke, movable means in the network movable as a function of unbalance of signals between the transformers and stopping when balance is attained, one of said actuating means being responsive to changes in the condition of a variable and the other being responsive to movement of the movable means, whereby network signal unbalance caused by changed output from one transformer is rebalanced by the complemental change of output from the other transformer with a differential between the lengths of the unbalancing and rebalancing respective strokes.

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