

June 2, 1953

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2,640,967

DIFFERENTIAL TRANSFORMER

Original Filed Nov. 24, 1948

Fig. 1.

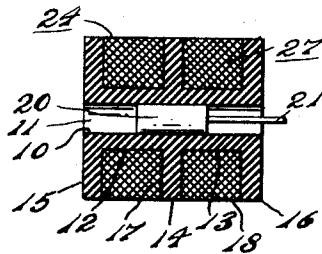
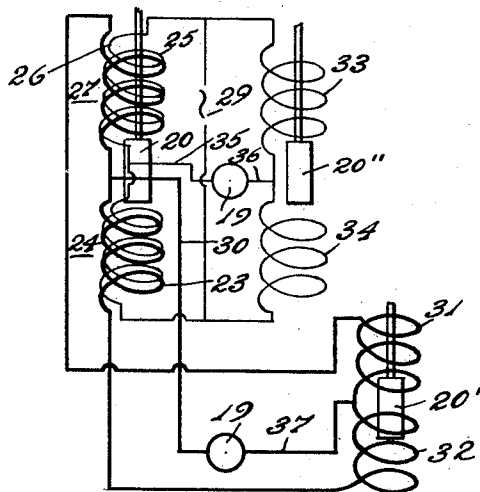


Fig. 2.



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2,640,967

DIFFERENTIAL TRANSFORMER

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Original application November 24, 1948, Serial No. 61,835, now Patent No. 2,568,587, dated September 18, 1951. Divided and this application August 31, 1951, Serial No. 244,484

1 Claim. (Cl. 336—136)

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This invention relates to differential transformers and constitutes a division of application Ser. No. 61,835, filed November 24, 1948, which issued as Patent No. 2,568,587, on September 18, 1951.

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 are 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

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perhaps of as much as a volt, or even higher, from the secondaries depending 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 transformers 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 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 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 interconnection 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 thereof being disclosed in detail, and showing the relatively movable armature in its cen-

centric 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.

Fig. 2 represents a diagram of the wiring of the transformer in an illustrative coupling for a bridge circuit arrangement.

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 Fig. 2, 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 diagram as one composite coil 24 of the transformer, and a primary winding 25 indicated by light lines comprising a third wire, and a secondary winding 26 indicated by the full lines in said diagram, 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 and 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 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 our 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. 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.

Fig. 2 represents the utilization of the windings described in both a voltage bridge circuit and an inductive bridge circuit. While these are combined in the differential transformer organization disclosed, comprising a dual transmitter feeding two measuring circuits, it will be seen that either circuit can be established to function as a single bridge circuit.

According to this figure the differential transformer secondaries comprise two legs of a voltage bridge circuit, the other half of which is formed by a voltage divider, and the output of which is controlled by the relative positioning of the armature 20 of the differential transformer, and the armature 20' of the inductively controlled voltage divider. Similarly, the primaries of the differential transformer power the voltage bridge and also comprise two legs of an inductive bridge circuit, the other half of which is comprised of a voltage divider, and the output of which is controlled by the relative positioning of the armature 20 of the differential transformer and the positioning of the armature 20'' of the primary circuit inductively controlled voltage divider.

The voltage bridge is comprised of the secondaries 23 and 26 which are in series aiding relation, as are the primaries 22 and 25. However, the adjacent ends of the secondaries have a common return path by a lead 30. The free ends of the secondaries are looped with the respective ends of the voltage divider comprised of coils 31 and 32 to form the voltage bridge, and the divider 37 completes, with lead 30, the bridge output circuit. With armature 20 positioned symmetrically of the interconnection of the secondaries 23 and 26 at 30, so that equal voltages are induced in the secondaries, and with the armature 20' relatedly positioned relative to the coils 31 and 32, the secondary output on one side of the interconnection in one secondary will be equal to and in phase with the voltage in the secondary on the other side of the interconnection. Displacement of the armature 20' will unbalance the voltages in the legs of the voltage bridge and cause a bridge output signal, which is neutralized or nullified by adjustments of the armature 20 in the proper sense or vice versa.

This is because movement of the armature toward one or the other secondary coil will increase the voltage output of that coil and decrease that of the other as a linear function of such movement.

The inductance bridge is similarly formed by the provision of a common return lead 35 forming the interconnection between primary coils 22 and 25, and the free ends of these coils are joined in a bridge circuit with a voltage divider comprised of coil legs 33 and 34, the divider 36 of which completes, with lead 35, the output of the inductance bridge, which is controlled by the relative positioning of the armatures 20 and 20', as will be understood.

In this case it will be clear that more windings than the two described could be used in connection with both coils.

In Fig. 2 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 bridge, 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. Movement of the armature in either direction induces a resultant bridge 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.

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.

Having thus described my invention, I claim:
A 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 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

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and fourth wires respectively in mutual inductive relation throughout the operative lengths of said wires in their 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 connectively isolated from the transformer primary comprising a common output connection for the second and fourth wires, said second and fourth wires having respective terminal output connections each respectively similarly spaced from and defining with the common connection substantially identical effective operative lengths of said second and fourth wires, a magnetic armature movable axially of the two aligned coils having one substantially symmetrical position therein at which the voltage of the effective operative length of said second wire is of

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substantially the same magnitude and phase as that of the effective operative length of said fourth wire, movement of said armature from said symmetrical position in either sense increasing the magnitude of the voltage in the operative length of that wire of the secondary toward which the armature moves while reciprocally decreasing that of the other wire of the secondary as a linear function of such movement.

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References Cited in the file of this patent
UNITED STATES PATENTS

Number	Name	Date
2,568,587	Macgeorge	Sept. 18, 1951
2,569,105	James	Sept. 25, 1951
2,570,672	Hathaway	Oct. 9, 1951