Jan. 16, 1962 J. CHASS 3,017,589

DIFFERENTIAL TRANSFORMER

Filed May 13, 1958

Fig. 1

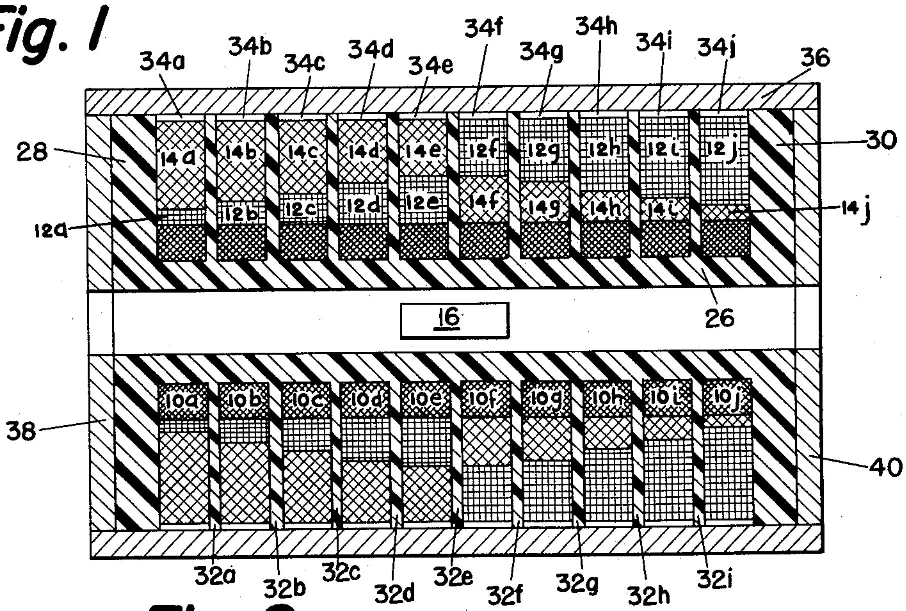
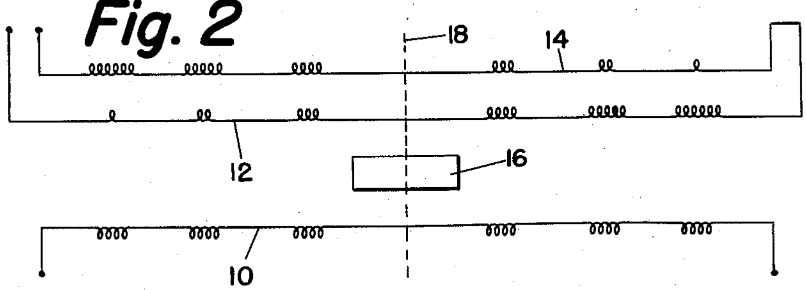


Fig. 2



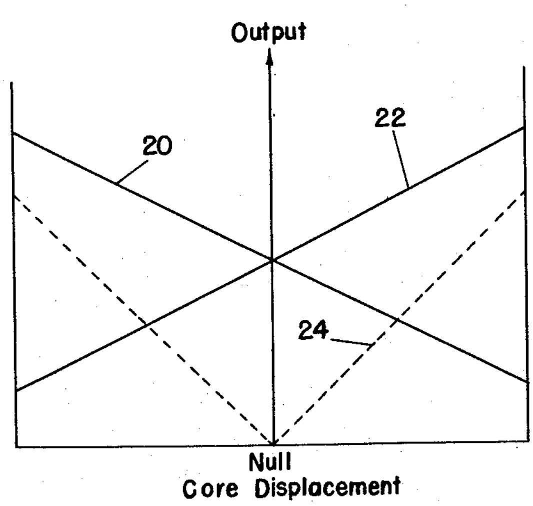


Fig. 3

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3,017,589

Patented Jan. 16, 1962

1

3,017,589
DIFFERENTIAL TRANSFORMER

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Filed May 13, 1958, Ser. No. 734,882
10 Claims. (Cl. 336—136)

This invention relates to the construction of a differential transformer and particularly to a differential transformer having a longer range of travel of the armature core.

Heretofore, differential transformers were composed of a tubular bobbin of non-conductive, non-magnetic material having three individual coils of conductive wire wound thereon in side-by-side relation and an armature core of magnetic material movably disposed within the bobbin as shown in United States Letters Patent No. 2,507,344. The center coil being primary coil and the two end coils, each of which is composed of the same number of turns, being the secondary coils with the secondary coils being connected in bucking series arrangement. By bucking series arrangement it is meant that the coils are connected so that when an A.C. current input is placed on the primary coil the output of one of the secondary coils is of an opposite phase to the output of the other secondary coil. When the armature core is in a position where it extends across the entire primary coil and projects beyond each end of the primary coil and across the same number of turns of each of the secondary coils it is at its null position, i.e., the output of each of the secondary coils is equal and of opposite phase so that the total output of the transformer is zero. If the armature core is moved in either direction from its null position it will extend across more turns of one of the secondary coils and less turns of the other secondary coil so that the output of the transformer increases. The maximum output of the transformer is obtained when the armature core has moved to a position where it still extends across the entire primary coil but projects only into one of the secondary coils. However, in such differential transformers, the maximum length of travel of the armature core from its null position to the position providing the maximum output of the transformer is small, being a maximum of ¼ the length of the transformer. Also, if the armature core is too long, it may, during its travel, extend beyond the end of the bobbin and interfere with the other equipment with which it is being used. However, for many applications of a differential transformer it is desirable to have a longer permissible length of travel of the armature core and still maintain the core entirely within the bobbin.

It is therefore an object of this invention to provide a construction of a differential transformer having a longer length of travel of the armature core. It is another object of this invention to provide a differential transformer having a longer length of travel of the armature core and still maintain the core within the bobbin at all times. It is still another object of this invention to provide a differential transformer in which the armature core can move a distance up to approximately one-half the length of the bobbin and still be within the bobbin. It is a further object of the invention to provide a differential transformer having a longer length of travel of the armature core which is constructed so that the core is always with the primary coil as well as both secondary coils. It is still a further object of this invention to provide a differential transformer having an increased range of movement of the armature core and in which the phase shift of the primary to secondary voltages is constant and the input impedance is constant. Other objects of the invention will in part be obvious and will in part appear hereinafter.

2

The invention accordingly comprises the features of construction, combination of elements and arrangement of parts, which will be exemplified in the construction hereinafter set forth, and the scope of the invention will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in connection with the accompanying drawing, in which:

FIGURE 1 is a longitudinal cross-sectional view of the differential transformer of this invention;

FIGURE 2 is a circuit diagram of the differential transformer; and

FIGURE 3 is a graph showing the output of the differential transformer with respect to the displacement of the armature core.

Referring to FIGURE 2 of the drawing, the differential transformer of this invention in general comprises an elongated primary coil **10** having a uniform number of turns per unit length, a first secondary coil **12** extending along the primary coil **10** and having an increasing number of turns per unit length from one end of the primary coil to the other end thereof, a second secondary coil **14** extending along the primary coil **10** and having a decreasing number of turns per unit length from the one end of the primary coil **10** to the other end thereof, and an armature core **16** of a magnetic material movably disposed within the coils. The increase in the number of turns per unit length of the first secondary coil **12** follows the same function as the decrease in the number of turns per unit length of the second secondary coil **14** and the two secondary coils are connected in bucking series arrangement. Since both secondary coils **12** and **14** are wound to follow the same function they are symmetrical about a line **18** approximately midway between the ends of the coils, i.e., the portion of first secondary coil **12** on one side of line **18** is the same as the portion of the second secondary coil **14** on the other side of line **18**. When armature core **16** is positioned with its midpoint on line **18** so that it projects an equi-distance beyond both sides of the line, core **16** will extend across the same number of turns of both secondary coils **12** and **14** and will be at its null point. Moving armature core **16** away from the null point in either direction places the core under a greater number of turns of one of the secondary coils and under a fewer number of turns of the other secondary coil but still maintains the core under the same number of turns of the primary coil, which is uniformly wound along the transformer. Thus, as the armature core **16** is moved away from the null point, the output of the transformer increases until the maximum output is obtained at the ends of the coils. This is shown graphically in FIGURE 3 in which line **20** indicates the output of only first secondary coil **12** with the displacement of the core and line **22** indicates the output of only second secondary coil **14**. Since the two secondary coils are in bucking series relation, dotted line **24** indicates the total output of the two coils which is zero at the null point and increases in both directions from the null point to a maximum at the ends of the coils. Although the output is shown to vary linearly, which is obtained by using a linear rate of change of turns per unit length for the secondary coils, it may follow any desired function by varying the turns per unit length of the secondary coils according to the desired function. Thus, the output of the differential transformer varies from zero to its maximum by moving the armature core **16** from its null point which is substantially midway between the ends of the coils, to either end of the coils so that the armature core **16** has a permissible displacement of approximately one-half the length of the coils without extending beyond the ends of the coils.

Referring to FIGURE 1, the preferred form of the differential transformer of this invention comprises a tubular bobbin **26** of a non-conductive, non-magnetic material, such as a plastic or ceramic material, having radially extending flanges **28** and **30**, one at each end thereof. Bobbin **26** also has a plurality of intermediate radial flanges, **32***a* to **32***i* respectively, equally spaced therealong between end flanges **28** and **30** and forming therebetween a plurality of compartments, **34***a* to **34***j* respectively. Although the bobbin **26** is shown to be provided with ten compartments, it may be provided with any even number of the compartments. First coils **10***a* to **10***j*, of insulated electrically conductive wire are helically wound around bobbin **26** in each of the compartments, **34***a* to **34***j* respectively. Each of first coils, **10***a* to **10***j*, are made up of the same number of turns and are connected together in series relation to form primary coil **10**. Second coils, **12***a* to **12***j*, of insulated electrically conductive wire, are helically wound around first coils, **10***a* to **10***j*, in each of the compartments **24***a* to **34***j*, respectively and are connected together in series relation to form first secondary coil **12**. The number of turns of each of the second coils **12***a* to **12***j* progressively increases from second coil **12***a* at one end of bobbin **26** to second coil **12***j* at the other end of the bobbin so that second coil **12***a* is made up of the least number of turns and second coil **12***j* is made up of the greatest number of turns. The rate of increase in the number of turns from one second coil to the next can be linear or follow any function according to the output which is desired from the transformer. Third coils, **14***a* to **14***j*, of insulated electrically conductive wire are helically wound around first coils, **10***a* to **10***j*, in each of the compartments **34***a* to **34***j*, respectively and are connected together in series relation to form second secondary coil **14**. The number of turns of each of the third coils **14***a* to **14***j* progressively decreases from third coil **14***a* at the one end of bobbin **26** to third coil **14***j* at the other end of the bobbin so that third coil **14***a* is made up of the greatest number of turns and third coil **14***j* is made up of the least number of turns. The rate of decrease in the number of turns from one third coil to the next follows the same function as the increase in turns of the second coils. Thus, secondary coils **12** and **14** are symmetrical about intermediate flange **32***e*. By the secondary coils being symmetrical it is meant that comparing the portions of the secondary coils in end compartments **34***a* and **34***j*, second coil **12***a* has the same number of turns as third coil **14***j* and third coil **14***a* has the same number of turns as second coil **12***j*. The same is true comparing the portions of the secondary coils in compartments **34***b* and **34***i*, **34***c* and **34***h*, **34***d* and **34***g* and **34***e* and **34***f*. As shown in compartments **34***a* to **34***e*, third coils **14***a* to **14***e* are wound over second coils **12***a* to **12***e* respectively but in compartments **34***f* to **34***j*, second coils **12***f* to **12***j* are wound over third coils **14***f* to **14***j*. The coils are arranged in this manner so that the intercoil capacitance will be the same for symmetrical coils and the flux density through symmetrical coils will be the same. Although in each compartment the secondary coil having the larger number of turns, is shown to be on top, the secondary coils can be reversed so that the coil having the least number of turns is on top so long as the symmetrical arrangement of the coils is maintained. Secondary coil **12** is connected to secondary coil **14** in bucking series arrangement by connecting either the end of second coil **12***a* to the end of third coil **14***a* or the end of second coil **12***j* to the end of third coil **14***j*. Armature core **16**, which is a rod of magnetic material, is movably disposed within bobbin **26**. If desired, a sleeve **36** of magnetic material can be placed around bobbin **26** and discs **38** and **40** of magnetic material placed against the end flanges **28** to **30** to shield the coils and to reduce the reluctance of the magnetic flux path. Although bobbin **26** is shown with intermediate flanges providing separate compartments for the various portions of the coils, the same arrangement of the coils can be provided on a bobbin which is not so divided.

In operation, when armature core **16** is positioned with its midpoint substantially within intermediate flange **32***e* so that core **16** extends across the same number of turns of the secondary coils in compartments **34***e* and **34***f*, the core **16** will be at its null position since the output of secondary coil **12** will be equal to the output of secondary coil **14** so that the total output of the transformer will be zero. Moving armature core **16** to the right from its null position as viewed in FIGURE 1, brings core **16** within more turns of secondary core **12** and less turns of secondary **14** but maintains core **16** within the same number of turns of primary coil **10** so that the total output of the transformer increases until a maximum output is obtained when core **16** is within the coils in end compartment **34***j*. Moving armature core **16** to the left from its null position likewise increases the total output of the transformer until a maximum output is obtained when core **16** is within the coils in end compartment **34***a*. Thus core **16** has a permissible displacement from its null position to a position providing a maximum output of substantially one-half the length of the transformer. In addition, since the phase shift of the primary to secondary voltages and the input impedance are both functions of the frequency, which is constant, the resistance of the primary coil which is constant, and the primary inductance and since armature core **16** always extends across the same number of turns of the primary coil **10** so that the primary inductance is constant, the phase shift of the primary to secondary voltages and the input imepdance are constant throughout the movement of the armature coil **16**.

It will thus be seen that the objects set forth above, among those made apparent from the preceding description, are efficiently attained and, since certain changes may be made in the above construction without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawing shall be interpreted as illustrative and not in a limiting sense.

It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention herein described, and all statements of the scope of the invention which, as a matter of language, might be said to fall therebetween.

Having described my invention, what I claim as new and desire to secure by Leters Patent is:

1. A differential transformer comprising the combination of a helically wound coil of electrically conducting wire having a uniform number of turns per unit length forming a primary coil, a second helically wound coil of electrically conducting wire over the full length of said coil forming a first secondary coil, said second helically wound coil having an increasing number of turns per unit length from one end of said first coil to the other end thereof, a third helically wound coil of electrically conducting wire wound over the full length of said first coil forming a second secondary coil, said third helically wound coil having a decreasing number of turns per unit length from said one end of said first coil to the other end thereof, said second coil being connected to said third coil in bucking series arrangement and an armature movably disposed within said coils.

2. The combination as set forth in claim 1 in which the increase in turns per unit length of said second coil follows the same function as the decrease in turns per unit length of said third coil.

3. A differential transformer comprising the combination of a tubular bobbin of non-conductive, non-magnetic material, a coil of electrically conductive wire helically wound along said bobbin and having a uniform number of turns per unit length to provide a primary coil, a second coil of electrically conductive wire helically wound along said bobbin over the full length of said

first coil to provide a first secondary coil, said second coil having an increasing number of turns per unit length from one end of said bobbin to the other end thereof, a third coil of electrically conducting wire helically wound along said bobbin over the full length of said first coil to provide a second secondary coil, said third coil having a decreasing number of turns per unit length from said one end of said bobbin to the other end thereof, said second coil being connected to said third coil in bucking series arrangement and an armature movably disposed within said bobbin.

4. The combination as set forth in claim 3 in which the increase in turns per unit length of said second coil follows the same function as the decrease in turns per unit length of said third coil.

5. The combination as set forth in claim 4 in which said third coil is wound over said second coil along approximately one-half the length of said bobbin and said second coil is wound over said third coil along the other one-half the length of the bobbin.

6. A differential transformer comprising the combination of a tubular bobbin of non-conductive, non-magnetic material having a radially extending flange at each end thereof and a plurality of longitudinally spaced radially extending flanges between said end flanges forming a plurality of compartments therebetween, a first coil of electrically conductive wire helically wound on said bobbin in each of said compartments, each of said first coils having an equal number of turns and being connected in series arrangement to provide a primary coil, a second coil of electrically conductive wire helically wound over said bobbin in each of said compartments, said second coils having an increasing number of turns from one end of said bobbin to the other end thereof and being connected in series arrangement to provide a first secondary coil, a third coil helically wound on said bobbin in each of said compartments, said third coils having a decreasing number of turns from said one end of the bobbin to the other end thereof and being connected in series arrangement to provide a second secondary coil, said first secondary coil being connected to said second secondary coil in bucking series arrangement, and an armature movably disposed within said bobbin.

7. The combination as set forth in claim 6 in which there are an even number of compartments along said bobbin.

8. The combination as set forth in claim 7 in which the increase in the number of turns of said second coils follows the same function as the decrease in the number of turns of said third coils.

9. The combination as set forth in claim 8 in which in one-half of the adjacent compartments from one end of the bobbin the third coil is wound over said second coil and in the other one-half of the compartments the second coil is wound over the third coil.

10. The combination as set forth in claim 9 including a tubular case of magnetic material fitting around said bobbin and a disk of magnetic material fitting against the outer surface of each end flange of said bobbin.

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