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C. M. MORRIS

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COIL FOR RELAYS AND INDUCTIVE APPARATUS

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FIG. 1

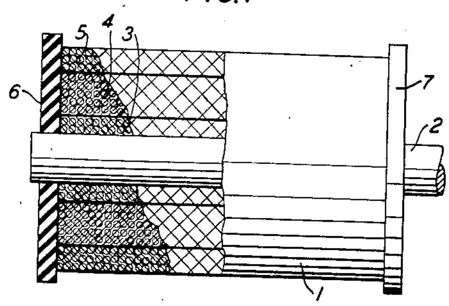
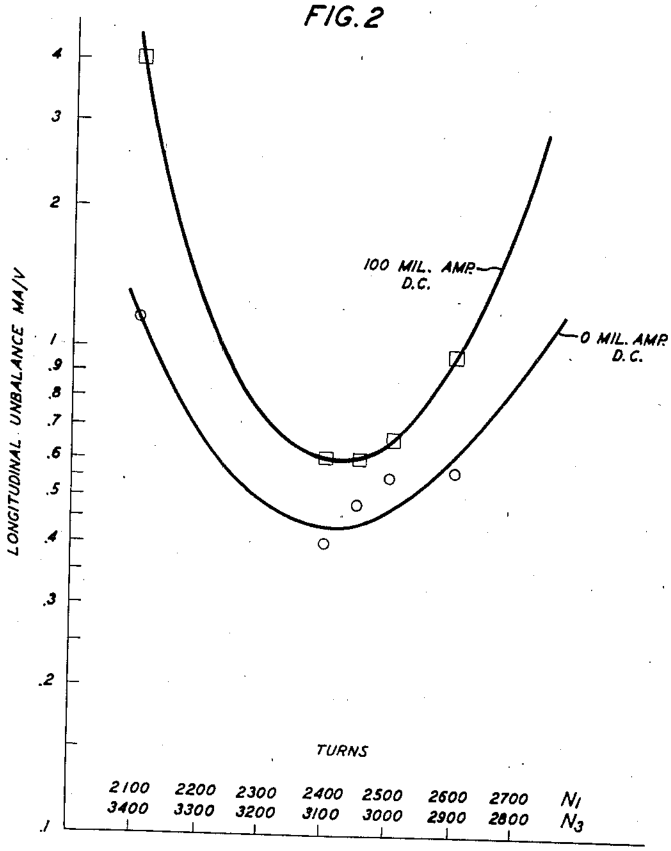


FIG. 2



INVENTOR
C. M. MORRIS
BY P. C. Smith
ATTORNEY

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COIL FOR RELAYS AND INDUCTIVE APPARATUS

Charles M. Morris, East Orange, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

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9 Claims. (Cl. 175—21)

This invention relates to coils for relays and other types of inductive apparatus and has for its object the securing of a high degree of longitudinal inductive balance.

Relays with two windings are used in large numbers in telephone systems with their two windings connected to the tip and ring conductors of the talking circuit and it is essential for quiet speech transmission that there shall be as small an inductive unbalance between the two windings as possible. Unbalances in relays now in general use have been found to be as high as 25 microamperes per volt.

Three different types of double wound relays and retardation coils have been used heretofore, the first of which is the tandem or front and rear winding type consisting of two coaxially adjacent windings each of which occupies the entire depth and approximately one-half the length of the winding space. Assuming that the two windings have an equal number of turns and similar dimensions, as is usually the case, it is obvious that the inductive balance is perfect provided that the magnetic structure is symmetrical lengthwise with respect to the two windings. However, practical considerations usually prescribe an unsymmetrical structure in which case the inductance of the two windings is inherently unbalanced. With any such actual structure, the effective symmetry and therefore the inductive unbalance are functions of the applied saturation.

The second type heretofore employed comprises two concentric windings each extending over the full length of the winding space. The chief advantage of this winding arrangement is the simplicity of manufacture, while the chief disadvantage is the rather poor balance under varied conditions of permeability of the magnetic structure. If a perfect magnetic structure, that is, one whose permeability approaches infinity, be assumed, it is then obvious that the inductive balance approaches perfection if the windings have an equal number of turns since all of the flux links all of the turns of each winding. When, however, the permeability of this type of structure is unity, that is, when an air core is used, the inductive balance is poor since the inductance of the outer winding is greater than that of the inner winding because the former has a larger radius. With the magnetic core material now used in relays of this type and with the various conditions of direct current saturation encountered, the inductive balance will, of course, lie between these two extremes. In general, however, the permeability for such relays will be no greater than ten even at the lowest voice frequencies encountered and the balance will be unsatisfactory for most types of transmission circuits.

The third type is known as sandwich wound and comprises three concentrically disposed windings, each extending over the full length of the winding space. The inner and outer windings have an equal number of turns and are connected in series to in effect constitute a single primary winding and the middle or secondary winding has a number of turns equal to or substantially equal to the sum of the turns of the other two windings. It is obvious that a coil wound in this manner is more symmetrical radially than the coil with two concentric windings and is more symmetrical lengthwise than the coil with tandem windings. In general therefore with any practical magnetic structure, a higher degree of inductive balance may be obtained with the sandwich type coil than with the tandem or with the two concentric winding coils. If the coil is provided with primary and secondary windings having an equal number of turns and those of the primary winding are equally divided between the inner and outer windings, the primary and secondary windings are well-balanced provided that the magnetic structure has high permeability, but not so well balanced if the permeability is low. In general this winding arrangement of the coil is poorly balanced for high values of direct current saturation. If the inner and outer windings constituting the primary winding have equal turns and the middle or secondary winding has about one per cent less turns than the sum of the turns of the other two windings, a better balance is secured since the inductances of the primary and secondary windings are more nearly equal at average values of direct current saturation, but an improvement in balance with this type of coil is still possible and desirable.

In accordance with the present invention, a higher degree of inductive balance is secured by providing an improved type of sandwich wound coil in which the inner and outer windings which constitute a single primary winding have, in general, an unequal number of turns, and the middle or secondary winding has a number of turns equal to the sum of the turns of the other two windings. Also the sum of the direct current resistances of the inner and outer windings equals the resistance of the middle winding.

Referring now to the drawing,

Fig. 1 shows a coil, partly in cross section, having its three windings proportioned in accordance with the invention, and

Fig. 2 shows curves graphically illustrating the longitudinal unbalance of variously wound coils.

Coils wound in accordance with the present invention meet the following four conditions which are necessary in order to insure optimum balance, namely: (1) perfect core balance; (2) air core balance; (3) symmetry of the primary and secondary windings along the length of the magnetic structure and, (4) direct current resistance balance. Fig. 1 illustrates a coil 1 wound in accordance with the invention mounted on a core 2 and having three windings 3, 4 and 5 wound concentrically and positioned on the core 2 between the fiber spoolheads 6 and 7. The numeral 3 designates the inner winding, 4 the middle or secondary winding and 5 the outer winding. Windings 3 and 5 are connectable in series to constitute the primary winding of the coil.

If L_1, L_2 and L_3 be assumed to be the inductances, N_1, N_2 and N_3 be assumed to be the number of turns of the windings 3, 4 and 5, respectively, and k_{13} the coefficient of coupling between the inner winding 3 and the outer winding 5, the condition for balance is expressed by the following equation:

$$L_1+L_3+2k_{13}\sqrt{L_1L_3}=L_2 \qquad (1)$$

Now let $L_1=\alpha_1N_1^2$, $L_2=\alpha_2N_2^2$ and $L_3=\alpha_3N_3^2$ where α_1, α_2 and α_3 are determined by the dimensions of the windings and by the magnetic structure. Substituting these values in Equation 1, the following equation is obtained:

$$\alpha_1N_1^2+\alpha_3N_3^2+2k_{13}N_1N_3\sqrt{\alpha_1\alpha_3}=\alpha_2N_2^2 \qquad (2)$$

If the core be perfect $\alpha_1=\alpha_2=\alpha_3$ and $k_{13}=1$, then Equation 2 reduces to

$$N_2=N_1+N_3 \qquad (3)$$

Substituting Equation 3 in Equation 2, rearranging and solving for

$$\frac{N_1}{N_3}$$

the following equation is secured:

$$\frac{N_1}{N_3}=\frac{\alpha_2-k_{13}\sqrt{\alpha_1\alpha_3}\pm\sqrt{k_{13}^2\alpha_1\alpha_3-2k_{13}\alpha_2\sqrt{\alpha_1\alpha_3}-\alpha_1\alpha_3+\alpha_1\alpha_2+\alpha_2\alpha_3}}{(\alpha_1-\alpha_2)} \qquad (4)$$

To satisfy both conditions 1 and 2 hereinbefore referred to, it is necessary for

$$\frac{N_1}{N_3}$$

to have the value given by Equation 4 when the factors k_{13}, α_1, α_2 and α_3 have their air core values. Since these factors are constant only for a particular set of dimensions, it is necessary to solve for

$$\frac{N_1}{N_3}$$

by a process of successive approximations. In the design of relays or retard coils other requirements usually fix the number of turns. The usual procedure is to assume a value of

$$\frac{N_1}{N_3}$$

which with the total number of turns fixes N_1, N_2 and N_3. Further assumption of the wire gauges fixes the dimensions so that the four factors may be computed by means of formulae such as have been determined by the United States Bureau of Standards. If as expected the substitution of these values in Equation 4 does not yield the original assumed value of

$$\frac{N_1}{N_3}$$

additional trials must be made until the computed and assumed values substantially agree.

Since the primary and secondary windings are concentric and wound to the same length, they are obviously symmetrical along the length of the magnetic structure and, therefore, meet the third aforementioned condition.

The direct current resistance of the primary and secondary windings may be approximately balanced to meet the fourth condition by selecting the proper wire gauges for each of the three windings. If this is not sufficiently close the direct current resistance may be balanced by adding a few non-inductive turns of resistance wire.

The improved winding arrangement has been applied experimentally to a battery supply relay coil for use in a transmission circuit of the step-by step telephone system where a high degree of longitudinal balance is required. From a circuit operation standpoint it is required that the relay windings have a total number of turns between 10,000 and 11,000 and a total direct current resistance R_{dc} between 360 and 440 ohms, these objectives to be secured with an approximately full wound coil spool.

A single approximation made in accordance with the method hereinbefore described indicated a value for

$$\frac{N_1}{N_3}=\frac{2}{3}$$

Since the formulae referred to are not sufficiently accurate to determine

$$\frac{N_1}{N_3}$$

precisely, the optimum value has been determined experimentally by measuring the unbalance of a few relays the coils of which were wound with different values of

$$\frac{N_1}{N_3}$$

each coil with a total of 11,000 turns and with No. 34 enamel covered wire for the inner winding, No. 33 enamel covered wire for the middle winding and No. 32 enamel covered wire for the outer winding. The specifications for the five coils are expressed in the following table:

Coil	Primary winding						Secondary winding middle	
	Inner		Outer		To 1 and 7			
	N_1	R_{dc}	N_3	R_{dc}	N_1+N_3	R_{dc}	N_2	R_{dc}
1	2,100	62	3,400	137	5,500	199	5,500	194
2	2,400	74	3,100	123	5,500	197	5,500	197
3	2,450	75	3,050	122	5,500	197	5,500	197
4	2,500	77	3,000	120	5,500	197	5,500	199
5	2,600	80	2,900	116	5,500	196	5,500	200

The curves of Fig. 2 have been plotted from values of longitudinal unbalance for each of the five experimental relay coils over the voice frequency for 0 and 100 milliamperes direct current saturation. From these curves it will be noted that the minimum unbalance occurs at approximately $N_1=2400$ turns. As might be expected the minimum for 0 millampere saturation is less well defined than for 100 milliamperes saturation since the former conditions more nearly approximate the perfect core in which the balance is independent of

$$\frac{N_1}{N_3}$$

It has thus been demonstrated that the minimum unbalance may be secured by proportioning the turns of the inner and outer windings so that the outer winding has the greater number of turns.

What is claimed is:

1. A coil for relays and similar devices having three concentric windings, the inner and outer of which have an unequal number of turns and are connectable in series to form a primary winding and the middle winding serving as a secondary winding and having a number of turns equal to the sum of the turns of the inner and outer windings.

2. A coil for relays and similar devices having three concentric windings of coextensive length, the inner and outer of which have an unequal number of turns and are connectable in series to form a primary winding and the middle winding serving as a secondary winding, and having a number of turns equal to the sum of the turns of the inner and outer windings.

3. A coil for relays and similar devices having three concentric windings, the inner and outer of which have an unequal number of turns and are connectable in series to form a primary winding and the middle winding serving as a secondary winding, and having a number of turns and direct current resistance equal to the sum of the turns and the sum of the resistances, respectively, of the inner and outer windings.

4. A coil for relays and similar devices having three concentric windings of coextensive length, the inner and outer of which have an unequal number of turns and are connectable in series to form a primary winding and the middle winding serving as a secondary winding, and having a number of turns and direct current resistance equal to the sum of the turns and the sum of the resistances, respectively, of the inner and outer windings.

5. In an electromagnetic device, a magnetic structure and a coil having three concentric windings, the inner and outer of which have a ratio of number of turns derived by the formula

$$\frac{N_1}{N_3}=\frac{\alpha_2-k_{13}\sqrt{\alpha_1\alpha_3}\pm\sqrt{k_{13}^2\alpha_1\alpha_3-2k_{13}\alpha_2\sqrt{\alpha_1\alpha_3}-\alpha_1\alpha_3+\alpha_1\alpha_2+\alpha_2\alpha_3}}{(\alpha_1-\alpha_2)}$$

in which α_1, α_2 and α_3 are determined by the dimensions of the windings and by the magnetic structure and k_{13} is the coefficient of coupling between the inner and outer windings, said inner and outer windings being connectable in series to form a primary winding and the middle winding serving as a secondary winding and having a number of turns equal to the sum of the turns of the inner and outer windings.

6. In an electromagnetic device, a magnetic structure and a coil having three concentric windings of coextensive length, the inner and outer of which have a ratio of number of turns derived by the formula

$$\frac{N_1}{N_3}=\frac{\alpha_2-k_{13}\sqrt{\alpha_1\alpha_3}\pm\sqrt{k_{13}^2\alpha_1\alpha_3-2k_{13}\alpha_2\sqrt{\alpha_1\alpha_3}-\alpha_1\alpha_3+\alpha_1\alpha_2+\alpha_2\alpha_3}}{(\alpha_1-\alpha_2)}$$

in which α_1, α_2 and α_3 are determined by the dimensions of the windings and by the magnetic structure and k_{13} is the coefficient of coupling between the inner and outer windings, said inner and outer windings, being connectable in series to form a primary winding and the middle winding serving as a secondary winding and having a number of turns equal to the sum of the turns of the inner and outer windings.

7. In an electromagnetic device, a magnetic structure and a coil having three concentric windings, the inner and outer of which have a ratio of turns derived by the formula

$$\frac{N_1}{N_3}=\frac{\alpha_2-k_{13}\sqrt{\alpha_1\alpha_3}\pm\sqrt{k_{13}^2\alpha_1\alpha_3-2k_{13}\alpha_2\sqrt{\alpha_1\alpha_3}-\alpha_1\alpha_3+\alpha_1\alpha_2+\alpha_2\alpha_3}}{(\alpha_1-\alpha_2)}$$

in which α_1, α_2 and α_3 are determined by the dimensions of the windings and by the magnetic structure and k_{13} is the coefficient of coupling between the inner and outer windings, said inner and outer windings being connectable in series to form a primary winding and the middle winding serving as a secondary winding and having a number of turns and direct current resistance equal to the sum of the turns and the sum of the resistances, respectively, of the inner and outer windings.

8. In an electromagnetic device, a magnetic structure and a coil having three concentric windings of coextensive length, the inner and outer of which have a ratio of number of turns derived by the formula

$$\frac{N_1}{N_3}=\frac{\alpha_2-k_{13}\sqrt{\alpha_1\alpha_3}\pm\sqrt{k_{13}^2\alpha_1\alpha_3-2k_{13}\alpha_2\sqrt{\alpha_1\alpha_3}-\alpha_1\alpha_3+\alpha_1\alpha_2+\alpha_2\alpha_3}}{(\alpha_1-\alpha_2)}$$

in which α_1, α_2 and α_3 are determined by the dimensions of the windings and by the magnetic structure and k_{13} is the coefficient of coupling between the inner and outer windings, said inner and outer windings being connectable in series to form a primary winding and the middle winding serving as a secondary winding and having a number of turns and direct current resistance equal to the sum of the turns and the sum of the resistances, respectively, of the inner and outer windings.

9. A coil for relays and similar devices having three concentric windings, the inner of which has approximately two-thirds as many turns as the outer winding, said inner and outer windings being connectable in series to form a primary winding and the middle winding serving as a secondary winding and having a number of turns equal to the sum of the turns of the inner and outer windings.

CHARLES M. MORRIS.