D. R. PRICE.

INDUCTANCE COIL.

APPLICATION FILED APR. 24, 1914.

1,213,689.

Patented Jan. 23, 1917.

2 SHEETS—SHEET 1.

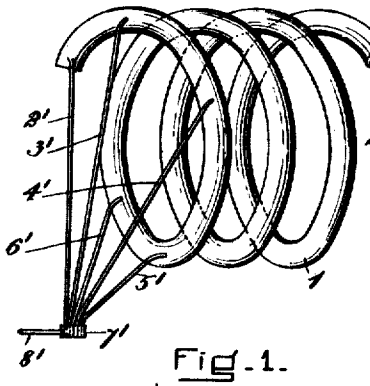


Fig. 1.

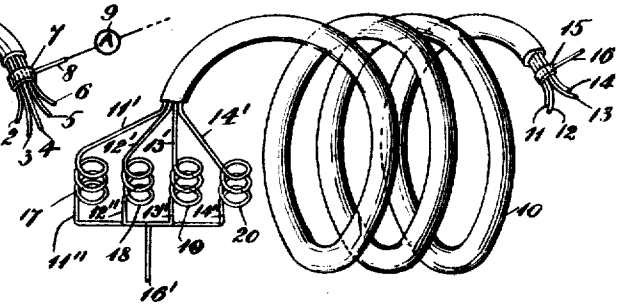


Fig. 2.

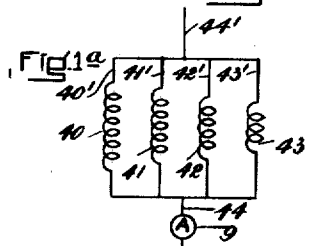


Fig. 1a.

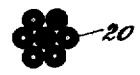


Fig. 3.

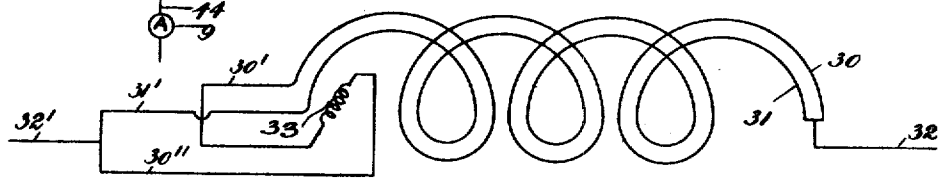


Fig. 4.

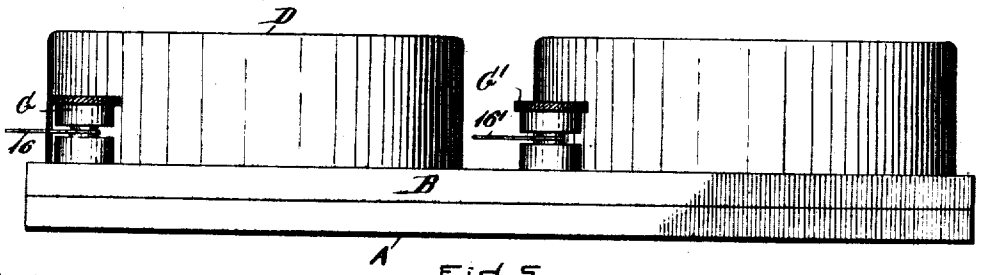


Fig. 5.

WITNESSES:

E. B. Tomlinson.

Patrick J. Conroy.

INVENTOR:

David R. Price

by Browne & Woodworth

Attys.

D. R. PRICE.

INDUCTANCE COIL.

APPLICATION FILED APR. 24, 1914.

1,213,689.

Patented Jan. 23, 1917.

2 SHEETS—SHEET 2.

Fig. 6.

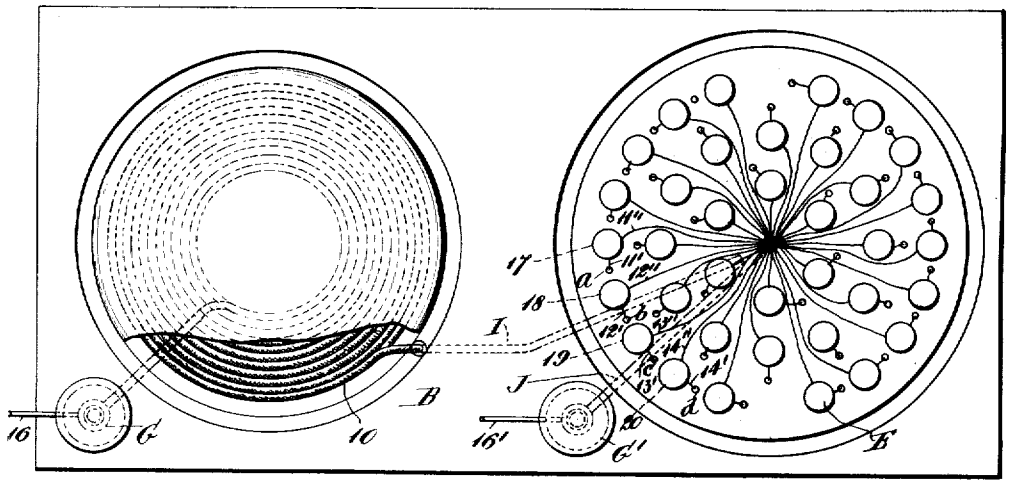
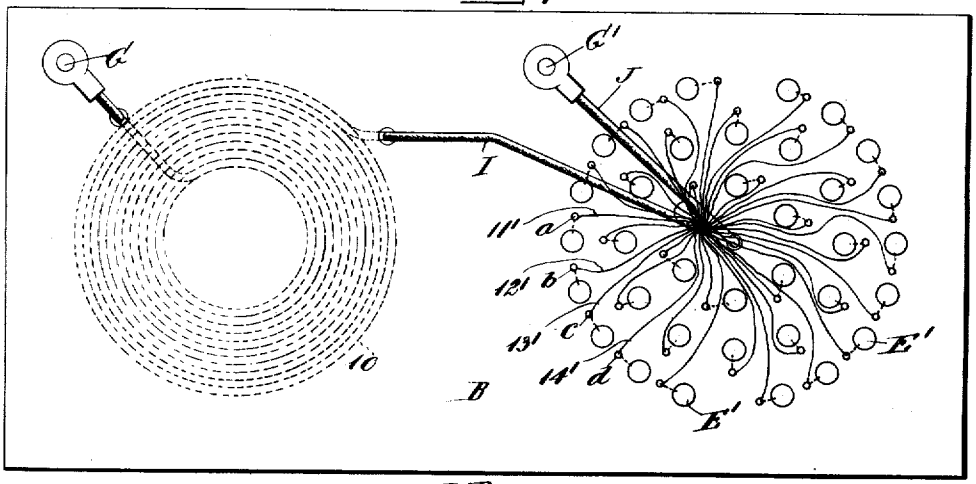


Fig. 7.



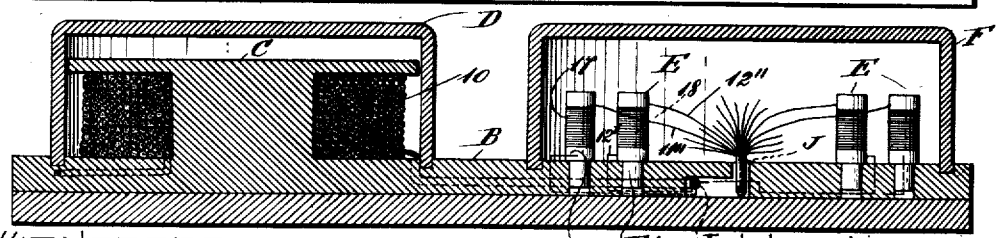


Fig. 8.

WITNESSES:

E. B. Tomlinson

Patrick J. Conroy.

INVENTOR:

David R. Price

by Browne & Woodworth

Attys.

UNITED STATES PATENT OFFICE.

DAVID R. PRICE, OF WINTHROP, MASSACHUSETTS, ASSIGNOR TO GEORGE K. WOODWORTH, TRUSTEE, OF BROOKLINE, MASSACHUSETTS.

INDUCTANCE-COIL.

1,213,689. Specification of Letters Patent. Patented Jan. 23, 1917.

Application filed April 24, 1914. Serial No. 834,095.

To all whom it may concern:

Be it known that I, DAVID R. PRICE, a citizen of the United States, and a resident of Winthrop, in the county of Suffolk and State of Massachusetts, have invented a new and useful Improvement in Inductance-Coils, of which the following is a specification.

The present invention relates to inductance coils, and while obviously capable of more general application, it has especial reference to coils used for tuning circuits, for example, space telegraph circuits, and for loading telephone or other lines.

The principal object of my invention broadly stated is to provide a coil which for a given inductance shall have a minimum or substantially a minimum resistance for use in alternating or other fluctuating current circuits, and this involves among other things the provision of means whereby the current shall divide itself equally or practically equally among the several strands making up the conductor employed for winding the coil.

Other objects of my invention are to improve the construction of inductance coils and increase the efficiency thereof for tuning circuits, loading lines, and for other purposes, in the manner hereinafter fully set forth.

The principle of my invention will be explained in connection with an illustrative embodiment of the same and several diagrams which are shown in the drawings accompanying and forming a part of this specification; although it will be understood that various modifications may be made both in the particular apparatus illustrated and specifically described and also in the several circuital arrangements.

In the drawings—Figure 1 is a diagram illustrating the principle of construction of an inductance coil embodying the present invention. Fig. 1ª is a diagram representing a modification of the construction shown in Fig. 1. Fig. 2 is a diagram representing in principle the preferred embodiment of the present invention. Fig. 3 is a cross-section of a stranded conductor that may be employed in another modification of my invention. Fig. 4 is a diagram illustrating the principle of a further modification. Fig. 5 is a front elevation of a coil constructed in accordance with the principle diagrammatically illustrated in Fig. 2. Fig. 6 is a plan view of the coil shown in Fig. 5. Fig. 7 is an inverted plan view of said coil. Fig. 8 is a longitudinal central section of the apparatus shown in Fig. 5.

Inductance coils used for tuning circuits, for loading telephone or other lines and for other purposes, should have a minimum of resistance to fluctuating current for a given inductance or a maximum of inductance for a given fluctuating current resistance and it is often desirable that for such maximum inductance and minimum fluctuating current resistance the coil should have the smallest possible volume.

By the term "fluctuating current resistance" of the conductor, I desire to be understood as meaning the opposition offered by such conductor to the flow of currents other than direct current of constant amplitude, for example, alternating current, oscillating current, and varying unidirectional current. In a circuit carrying fluctuating current, the absorption of power is obtained by multiplying the square of the current by the fluctuating-current resistance, the resulting product commonly being called the "C^2R loss." In this expression for the C^2R loss, the factor R includes ohmic resistance, "skin effect", eddy current loss, etc., and its value cannot be obtained by dividing electromotive force by current, but only by means of a watt meter and an ammeter and a source of fluctuating current. It is the fluctuating resistance defined as above that I reduce to a minimum in a coil having a given inductance. Throughout the specification, where the word "resistance" occurs without qualification, it is to be understood that I mean fluctuating-current resistance. In wireless telegraphy the inductance or tuning coils constitute one of the chief sources of loss, both in the sending and receiving apparatus, and it is well known that such apparatus are made more efficient and more selective, and static disturbances are more readily eliminated, when the tuning coils have the smallest practicable resistance and volume per unit of inductance. Also in loaded lines it is necessary not only to reduce the resistance of a loading coil to the lowest practicable value per unit of inductance but also to make the volume of the coil as small as possible; but it will be understood that my invention is applicable to coils of all proportions and is not necessarily limited to an ideal or mathematically

perfect coil which has maximum inductance and minimum resistance per unit of cubical contents. Coils used for these purposes in circuits carrying high frequency alternating current are usually made of stranded conductors consisting of a number of fine-wire enamel-insulated strands connected in parallel, the fine-wire being employed to reduce the skin effect and cut down eddy currents, and the necessary cross-section for carrying a given current being obtained by the connection of a number of strands in parallel. Great care has been taken to wrap or braid the strands in such manner that each is symmetrically placed in the bundle, with the object that each strand should be as much on the surface of the bundle as it is in the center, so that the total resistance of the conductor shall be reduced in proportion to the number of strands so connected in parallel. I have discovered, however, that it is not possible, even by the exercise of the greatest skill and care in the manufacture of a stranded conductor to reduce the resistance in proportion to the number of strands employed by mere symmetrical arrangement to the strands; and I have found that in order to obtain such proportional reduction in resistance for the production of a coil having a minimum or substantially a minimum resistance for a given inductance, or a maximum inductance for a given resistance it is necessary to depart widely from the methods heretofore employed and apply the principle herein set forth.

However, before particularly setting forth this principle and specifically describing apparatus based thereon, I shall proceed to explain in detail the reasons why the coils of the prior art cannot be used to attain the object of the present invention using as an illustration a coil which I prepared in the following manner: Six strands of enamel-insulated copper wire .003 of an inch in diameter were accurately measured and twisted by machine into a cable about a center core of silk, thereby eliminating the straight wire which usually is employed for the center and obtaining a stranded conductor or cable, the strands of which were disposed as symmetrically as possible. The stranded conductor or cable so obtained was then cut into six lengths, and the six cables then twisted about a silk center in the direction opposite to that in which the strands originally were twisted. The complete cable formed in this manner was to all appearances perfect with respect to the symmetry of arrangement of the thirty-six strands making up the same. A coil was then wound with the cable so formed and I found that in spite of the care and high degree of accuracy employed, it was impossible to be sure of getting even good results and I could never get perfect results. After investigation I discovered why the coil above described failed to give good results and I also ascertained the condition prerequisite for obtaining a minimum or substantially a minimum resistance per unit of inductance for a coil wound with a stranded conductor having a given total cross-section of wire. The reason why good results were not obtained is that the several strands of wire connected in parallel did not carry equal portions of the total current whereas the condition necessary for obtaining a minimum or substantially a minimum resistance per unit of inductance for a coil wound with a stranded conductor having a given total cross-section of wire is that the total current must be divided equally or substantially equally among the strands used to make up the cable.

When a stranded conductor or a conductor made up of strands of wire connected in parallel is wound into a coil, the total current will in general divide itself unequally among the several strands for reasons which I shall now proceed to explain, using for illustration a two-layer coil, each layer being wound with a single strand of wire and the two strands, that is to say, the two layers being connected in parallel. If the two strands are wound very closely and compactly, for the sake of my illustration one may neglect the difference in the diameters of the layers and assume that the inductance of the separate layers depends only on the number of turns thereof; but it will be understood of course that in actual practice such difference in diameters cannot be neglected, as hereinafter pointed out. The mutual inductance of the two layers in this case is practically unity. If the inner layer or strand have fifty turns and the outer fifty-one, the outer layer or strand will have a larger counter electromotive force generated in it than the inner, the counter electromotive force of the two layers being almost in the ratio of turns or 51:50. Inasmuch as the counter electromotive force of the inner layer is equal to the impressed electromotive force, it follows that the counter electromotive force of the outer layer is larger than the impressed electromotive force in substantially the ratio 51:50, and this results in a counter current flowing in the outer layer, such counter current producing more loss in the system than if only a single layer or strand had been used instead of two connected in parallel. In other words, the resistance of the coil consisting of two strands or layers connected in parallel, instead of being less than that of a single strand or layer as the prior art teaches,—theoretically, only one-half as great,—is actually higher than that of a single strand or layer.

I shall now more fully explain the limita-

tions to which the coils of the prior art are subject by taking as an illustrative example a more practical inductance coil or one which conforms more closely than the one used in the foregoing illustration to the coils actually employed in the electric arts. I shall assume that the coil used for this illustration is wound on a hard rubber core about 2 inches in diameter with a stranded conductor consisting of two strands connected in parallel and that it has fifteen layers of ten turns each. I shall further assume that the resistance of each of the strands before it is twisted around the other is 30 ohms and that the total resistance of the stranded conductor consisting of the two strands in parallel is 15 ohms before it is wound into the coil. A coil so constructed will have an inductance of about 1 millihenry. If an alternating current of I ampere having a frequency of 1,000,000 cycles per second energizes the coil, the potential difference across the terminals of the coil will be 6000 volts. I shall now assume, as is frequently the case, that the two turns are not exactly equal in length. If strand A be one per cent. longer than strand B, it will have 151.5 turns and strand B 150 turns. Strand B will have a voltage drop of 40 volts per turn, and since the resistance of each strand separately is only 30 ohms, the counter voltage drop will be almost equal to the impressed voltage drop or substantially 40 volts per turn. Inasmuch as strand A is wound very close to strand B, it also will have a counter voltage drop of 40 volts per turn or 6060 volts across its terminals. Thus the counter electromotive force of strand A is greater by 60 volts than its impressed electromotive force and a counter current is obtained therein, such counter current being relatively large because the resistance of strand A is relatively small, being as aforesaid only 30 ohms. From this example it will be seen that even so slight a variation as one per cent. in the length of a strand is sufficient not only to cause the total current to divide unequally between the strands, but to make the current actually flow backward in one of them. The same thing occurs in an inductance coil which is wound with a conductor made up of more than two strands. It will be obvious that an unsymmetrical arrangement of the strands will have the same effect as inequalities in the lengths thereof.

Having thus shown by reference to two typical coils of the prior art the existence of a problem that must be solved in order to produce a coil having maximum inductance for a given resistance, or a minimum or substantially a minimum resistance for a given inductance, I shall now proceed to describe several methods whereby I have succeeded in solving said problem and in realizing my invention in practice; but it is to be understood that the principle underlying the present invention may be practically applied in various other and equivalent ways which I consider unnecessary to disclose herein.

First method.—Referring to Fig. 1, the inductance coil 1 is represented as made up of the strands 2, 3, 4, 5, 6, insulated preferably by enamel, which are electrically connected together at one end by the clamp 7 to form the terminal 8 of the coil. A certain length of the outside insulation is first removed from the other end of the stranded conductor. An ammeter 9 is then connected in series with the terminal 8, a source of high-frequency current (not shown) and the other terminal of the coil 8′, the latter being connected to the clamp 7′, and the circuit so formed preferably being tuned to the frequency of said current. The end 2′ of strand 2, which may be any one of the several strands, is then connected to said clamp 7′, without unwinding any portion thereof from the coil, so that this one strand is now in series with the ammeter and source of electromotive force. The reading of the ammeter is noted and then the end 3′ of any other strand, for example strand 3, is connected with the clamp 7′ so that it is in parallel with the strand 2 and adjusted as shown by unwinding a portion thereof from the coil, or else by winding an additional length thereof on the coil, as the case may be, until the ammeter shows a maximum reading. The end 4′ of a third strand, such for example as 4, is then connected in parallel with strands 2 and 3, and partially unwound from the coil or an additional length wound thereon as required until maximum reading of the ammeter is obtained, and so on, one after another, until all the strands, herein shown as five in number, but in practice usually a much larger number, are connected in parallel to the coil terminals 8 8′. The insulation previously removed is then replaced, as shown in Fig. 1. In this manner all the strands are independently adjusted to insure the equalization of their impedances and counter electromotive forces, and when such equalization has been effected the total current flow will be divided equally among the several strands and the resistance of the coil, consisting as aforesaid of a plurality of strands connected in parallel, will be a minimum. The coil will then have a minimum resistance for a given inductance or a maximum inductance for a given resistance.

The method described in connection with Fig. 1 may be carried out in several different ways, for example in the following manner: Fig. 1[a] represents a coil which I have successfully employed for practising the present invention and which has an inside diameter of 3 3/4 inches and an axial length of

2 5/8 inches, being wound in four layers 40, 41, 42, 43, one on top of the other, each consisting of 100 turns of No. 30 B. & S. enamel-insulated wire. The terminals 40′ 41′ 42′ 43′ of each layer are brought out separately as shown. The four layers are connected in parallel with the terminals 44, 44′, and an ammeter 9 connected in series with the coil and a source of high frequency current, the circuit so formed preferably being tuned to the frequency of said current. The resistance of each layer was 8.68 ohms and the four layers connected in parallel had the same resistance as any one layer as originally wound and before adjustment when the coil is used in such high frequency alternating current circuit. In order to adjust this coil for minimum resistance and insure the equal division of alternating current among the several layers, the latter were adjusted as follows: First, the bottom layer 40 was connected in series with the source of alternating current and the ammeter 9 and the ammeter reading noted. The second layer 41 was then connected in this circuit in parallel with the bottom layer and adjusted by unwinding some of its turns from the spool. When about two turns were unwound, the maximum ammeter reading was obtained showing that minimum resistance had been reached, such minimum resistance being 1.48 ohms. The third layer 42 was then connected in parallel with the other two layers and about four of its turns unwound, whereupon the ammeter showed a maximum reading and the resistance of the system was reduced to 3.03 ohms. The top layer finally was connected in parallel with the other three and about six turns unwound to obtain the maximum ammeter reading, and when this was done the resistance of the system was reduced to 2.49 ohms, which it will be seen is slighuly larger than one-quarter of the resistance of a single coil. The four layers after adjustment had equal counter electromotive forces and the total current flow was divided equally among the several layers when the bottom layer 40 had 100 turns, the next about 98 turns, the next about 96 turns, and the top layer about 94 turns. The adjustment obtained was extremely fine being within 1/8th of one turn or about 1/8th of one per cent. of the total length of the wire. In this coil also the resistance is a minimum for a given inductance or the inductance a maximum for a given resistance.

As an example of the efficiency of a coil constructed and adjusted in the manner above set forth in connection with Fig. 1ª, I will give the following data obtained from a coil wound in layers with 16 strands of No. 36 B. & S. enamel-insulated copper wire connected in parallel and having a volume of 1 1/8 cubic inches, in comparison with a single layer standard coil No. 24 B. & S. copper wire wound in grooves in a hard rubber cylinder four inches in diameter, the turns being 1/32 inch between centers and the whole coil having a volume of 48 cubic inches. The resistance of my coil was thirty per cent. less than that of the standard coil for currents having a frequency of 100,000 cycles per second and it tuned the circuit in which it was connected as sharply as the standard coil. My coil was then immersed in oil having a higher specific inductive capacity than air, without altering the sharpness of the tuning of the circuit in which it was connected, thereby showing conclusively the absence of any of the bad effects of distributed capacity. This is a very important characteristic of my invention because it renders possible the use in tuned circuits of layer-wound coils which effect a still further reduction of resistance.

Second method.—Referring to Fig. 2, the ends of the strands 11, 12, 13, 14, shown for convenience of representation as four in number, although in practice many more are employed, are electrically connected by the clamp 15 or other suitable means to the terminal 16 of the coil 10. The other ends 11′, 12′, 13′, 14′ of the strands are respectively connected with one end of the small inductance coils 17, 18, 19, 20, the other ends 11″, 12″, 13″, 14″ of said inductance coils being connected to the other terminal 16′ of the system. It will be understood of course that the strands 11, 12, 13, 14 are separately insulated, preferably enamel-insulated, and they are disposed as symmetrically as possible. The resistance of each of the strands is small compared with the reactance of the main coil for frequencies of the order of those with which a coil of this nature is to be employed. Therefore any small excess counter electromotive force in a strand, resulting from inequalities in the length of the strands or other cause, will diminish or prevent the flow of current through said strand or even produce a counter current therein. If, however, such strand has a separate impedance such as the coil 17 connected in series with it, the counter voltage generated in said strand will not prevent the flow of current therethrough, much less produce a counter current, unless such counter voltage be very much larger than that which would be required to effect these undesirable results were no such separate impedance employed, because the voltage drop across said separate impedance acts as a voltage-regulator for its particular strand.

It will therefore be seen that in my second method a separate impedance not common to the whole number of strands is connected in series with each individual strand and that the counter electromotive forces and

impedances of the several strands need not be exactly equal. In fact I have found that the reactance regulators or separate inductance coils 17, 18, 19, 20 even when very small will compensate for differences as high as two per cent. in the impedances of the several strands. It will be noted that no C^2R losses result from the use of a reactance regulator, and therefore such reactance regulator is preferable to a resistance regulator. In this case also the resistance of the coil is a minimum for a given inductance and the resistance of the entire system between the terminals 16, 16′ is substantially a minimum for a given inductance.

Third method.—As will be obvious, the result accomplished by the apparatus above explained in connection with Fig. 2, may be attained by the simple expedient of providing each separate strand with an abnormally thick insulation, such insulation giving each strand the necessary separate reactance, in which case separate reactance regulators such as the coils 17, 18, 19, 20 need not be employed. A stranded conductor composed of a plurality of symmetrically-arranged strands, in this case six wound around a silk core, each provided with an unusually thick insulation 20, is shown in Fig. 3 and such stranded conductor or cable may be wound into an inductance coil for carrying out my third method. I do not, however, prefer this construction because of the bulk of the coil produced in this manner, but if there is no object in reducing the volume of the coil, the arrangement shown in Fig. 3 may be used and it will effect the desired equalization of current in the several strands. In this case, the greatly increased separate distributed inductance of each strand resulting from the abnormally thick insulation performs the same function and accomplishes the same result as the lumped-reactance-regulators shown in Fig. 2 and does so in substantially the same manner.

Fourth method.— As will be obvious, the separate strands may be adjusted to produce a maximum of inductance for a given resistance or a minimum of resistance for a given inductance by compensating for inequalities in counter electromotive force and impedance by introducing into one or more strands a separate inductance which has mutual inductance with the main coil wound from the stranded conductor. In Fig. 4 the strands 30, 31, insulated one from the other and connected in parallel, are wound into a coil the terminals of which are shown at 32, 32′. The end 30′ of the strand 30 is connected to one terminal of the small inductance coil 33, the other terminal of which is connected by the conductor 30″ to the terminal 32′ of the system, the end 31′ of the strand 31 being also connected to said terminal 32′. If the two strands have different impedances for alternating currents of a given frequency, the reactance regulator 33 connected in series with the strand having the smaller impedance will compensate for such inequalities of impedance by means of its mutual inductance with respect to the main coil. The exact position of the reactance regulator 33 with respect to the main coil may be determined as follows: Connect between the terminals 32, 32′ an ammeter, source of fluctuating current, and, preferably, a condenser so adjusted as to put the system in resonance with the frequency of said current, bring the reactance regulator near the main coil, and by experiment ascertain the position of the regulator which will give a maximum reading of the ammeter indicating minimum resistance for the two strands 30, 31 in parallel and secure the regulator in such position. The advantage of this method is that the reactance regulator need not be so large in volume or impedance, and therefore in resistance, as if its self-inductance were relied upon entirely for compensation. I have found that the reactance regulator in this case need have a resistance of only about one per cent. of the total resistance of the main coil, while those employed in my second method each have an ohmic resistance of from three to five per cent., of the total ohmic resistance of the main coil.

It will be understood of course that it is my object to secure the equal or substantially equal division of current among the several strands which make up the cable or stranded conductor used to wind an inductance coil only when the strands, as is usually the case, are all of the same or practically the same size. It will be obvious that if the cables are made up of wires of different sizes, for example No. 24 B. & S. and No. 36 B. & S., the strands are to be so adjusted by any one of the methods herein set forth that the impedances thereof and the current flow therein shall be proportional to the cross-sectional areas of the strands. In this case, just as where the strands are of the same size, the reactance regulators compensate for the effect of any inequalities of impedances of the several strands which may be disproportionate to the respective cross-sectional areas thereof, so that current flowing through the strands shall be proportional to the respective cross-sectional areas of the strands, and the resistance of the coil made a minimum or substantially a minimum for a given inductance. It will further be understood that when coils constructed in accordance with the present invention are used with high frequency alternating currents, paramagnetic cores preferably are not employed and that such cores may be used

when the coils are employed with low frequency alternating currents.

I shall now describe one illustrative embodiment of my invention which I have successfully employed in practice to carry into effect my second method, without, however, limiting my invention thereto, for it will be obvious that various other types of apparatus may be devised by those skilled in the art for this purpose. Referring to Figs. 5, 6, 7 and 8, A represents a base of wood or other suitable non-conducting material, to which may be attached in any suitable manner a block B provided with a spool C having a cap or cover D. The coil 10 is wound upon the spool and in the present instance is shown as having eleven layers of eleven turns each of a cable formed by twisting together thirty-six strands of enamel-insulated wire about .003 inch in diameter, the ends of said strands all being electrically connected with a clip soldered to the binding post G. The stranded conductor I from the outer end of the coil passes through a groove in the block B to a point near the center of the right hand half of said block and the separate strands 11′, 12′, 13′, 14′ which form the conductor, are led through the holes *a*, *b*, *c*, *d* to the upper face of the block B and are connected with the reactance regulators 17, 18, 19, 20, respectively. The other terminal of each reactance regulator is connected to the strands 11″, 12″, 13″, 14″, respectively, which compose the stranded conductor J passing through a hole in the block B leading to a clip on the under side of said block which is electrically connected with the binding post G′. In the present instance there are thirty-six separate impedance coils or reactance regulators 17, 18, 19, etc., each wound with a single strand of wire which may be identical with the strands making up the conductor I of the coil 10. Each reactance regulator is wound on a pin E about 3/16 of an inch in diameter and 1/4 of an inch in length, and each containing six feet of wire wound in three layers. The lower end of each pin is shouldered as shown at E′ and secured in a hole in the block B. The reactance regulators as shown may conveniently be arranged to occupy a circular space and this space in the present instance is provided with a cap or cover plate F.

The strands of the coil 10 are arranged as symmetrically as possible, preferably about a silk center. The resistance of the coil for currents of high frequency, about 100,000 cycles per second, without any such adjustment as described in connection with Fig. 1, and without the addition of the separate inductances 17, 18, etc., was extremely high. Instead of being 1/36 of the resistance of an individual strand, it was about equal to four of said strands in parallel, that is to say about 1/4 the resistance of a single strand. However, when I connected to each strand one of the small inductances 17, 18, etc., as aforesaid, the resistance of the coil was found to be equal to the resistance of thirty-six strands in parallel, in other words, about 1/36 that of a single strand, and therefore the action of the coil in high frequency circuits is almost perfect.

Having thus disclosed the principle on which my invention is based and specifically described one practical embodiment thereof, without, however, limiting my invention to said embodiment, what I claim as new and desire to secure by Letters Patent is—

1. The method of reducing to substantially a minimum the fluctuating current resistance of an inductance-coil wound with a stranded conductor and having a given inductance which consists in compensating for the effect of inequalities of the impedances of the several strands making up said conductor.

2. The method of reducing to substantially a minimum the fluctuating current resistance of an inductance coil wound with a stranded conductor and having a given inductance which consists in compensating for the effect of any inequalities of the impedances of the several strands making up said conductor which may be disproportionate to the respective cross-sectional areas thereof.

3. The method of giving a stranded-wire inductance-coil substantially minimum fluctuating current resistance for a given inductance which consists in rendering practically equal the impedances of the several strands making up the conductor employed for winding said coil and compensating for the effect of any inequalities of the impedances of said strands.

4. The method of giving a stranded-wire inductance coil substantially minimum fluctuating current resistance for a given inductance which consists in rendering the impedances of the several strands making up the conductor employed for winding said coil practically proportional to the respective cross-sectional areas thereof and compensating for the effect of any inequalities of the impedances of said strands which may be disproportionate to their respective cross-sectional areas.

5. An inductance-coil comprising in combination a main coil wound with a stranded-wire conductor and having a given inductance and means for reducing to substantially a minimum the fluctuating current resistance of said coil.

6. An inductance-coil comprising in combination a main coil wound with a stranded-wire-conductor and having a given inductance and means whereby the total current energizing said coil is caused to divide itself substantially equally among the several strands making up said conductor, whereby

the fluctuating current resistance of said coil is reduced to substantially a minimum.

7. An inductance-coil comprising in combination a main coil wound with a stranded-wire conductor and a voltage regulator associated with each of the several strands making up said conductor.

8. An inductance-coil comprising in combination a main coil wound with a stranded-wire conductor and a reactance regulator associated with each of the several strands making up said conductor.

9. An inductance-coil comprising in combination a main coil wound with a stranded wire conductor and a plurality of smaller coils each connected in series with a different one of the strands making up said conductor.

10. In an inductance-coil, a non-conducting base, a spool carried thereby, a main coil formed of a stranded-wire conductor wound on said spool, a plurality of smaller spools supported by said base, a coil wound on each of said smaller spools, each of the last mentioned coils being very much smaller than said main coil, a terminal member for one end of said main coil, a length of said stranded-wire conductor leading away from the other end of said main coil, means electrically connecting one terminal of each of the last mentioned coils with a different one of the ends of the strands of said length of conductor so leading away from said other end of said coil, and other means electrically connecting each of the other terminals of the smaller coils with a common terminal, whereby the system included between said common terminal and said terminal member shall have substantially a minimum of fluctuating current resistance for a given inductance.

11. In an inductance-coil, a support, a main coil secured thereto and wound with a conductor made up of a plurality of insulated strands, a plurality of much smaller coils each connected in series with a different one of said strands, whereby the effective impedances of the several strands making up said conductor are rendered practically equal and the fluctuating current resistance of said main coil reduced to substantially a minimum and means securing said smaller coils to said support.

12. In an inductance-coil, a support, a main coil secured thereto and wound with a conductor made up of a plurality of insulated strands, a plurality of much smaller coils each connected in series with a different one of said strands, whereby the effective impedances of the several strands making up said conductor are rendered substantially proportional to the respective cross-sectional areas of said strands and the fluctuating current resistance of said main coil reduced to substantially a minimum, and means securing said smaller coils to said support.

13. An inductance-coil formed of a conductor made up of a plurality of insulated strands and means for substantially equalizing the current flowing through the separate strands whereby said coil is given substantially a minimum fluctuating current resistance for a given inductance.

14. An inductance coil formed of a conductor made up of a plurality of insulated strands and means for rendering the current flowing through the separate strands substantially proportional to the respective cross-sectional areas thereof whereby said coil is given a substantially minimum fluctuating resistance for a given inductance.

15. The method of reducing to substantially a minimum the fluctuating current resistance of an inductance-coil wound with a stranded wire conductor which consists in compensating for the inequalities of the counter electromotive forces of the several strands making up said conductor by creating other counter electromotive forces each in a different one of said strands which are large compared to the counter electromotive forces due to the ohmic resistance of each separate strand.

16. The method of reducing the fluctuating current resistance of an inductance-coil, wound with a stranded conductor, to substantially length of the fluctuating-current resistance of each strand making up said conductor, where n represents the number of such strands and the cross-sections of said strands are substantially equal, which consists in compensating for the effect of inequalities of the impedances of the several strands making up said conductor.

17. An inductance coil formed of a conductor made up of a plurality of insulated strands and means for compensating for the effect of inequalities of the impedances of the said strands, whereby said coil is given substantially a minimum fluctuating current resistance for a given inductance.

18. An inductance coil formed of a conductor made up of a plurality of insulated strands and means for compensating for the effect of the inequalities of the impedances of said strands which are disproportionate to their respective cross-sectional areas, whereby said coil is given substantially a minimum fluctuating current resistance for a given inductance.

In testimony whereof, I have hereunto subscribed my name this 22nd day of April, 1914.

DAVID R. PRICE.

Witnesses:
GEO. K. WOODWORTH,
E. B. TOMLINSON.

Correction in Letters Patent No. 1,213,689.

8

It is hereby certified that in Letters Patent No. 1,213,689, granted January 23, 1917, upon the application of David R. Price, of Winthrop, Massachusetts, for an improvement in "Inductance-Coils," an error appears in the printed specification requiring correction as follows: Page 7, line 96, claim 16, for the word "length" read $1/n^{th}$; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 13th day of February, A. D., 1917.

[SEAL.]

R. F. WHITEHEAD,
Acting Commissioner of Patents.

Cl. 171—242.