May 17, 1966 A. V. HUGHES 3,252,118

ELECTROMAGNETIC INDUCTION APPARATUS

Filed June 2, 1958 2 Sheets-Sheet 1

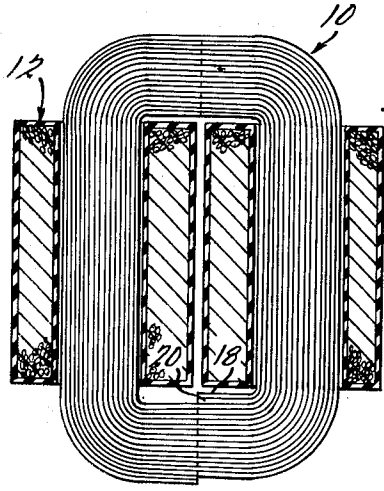



FIG. 1.

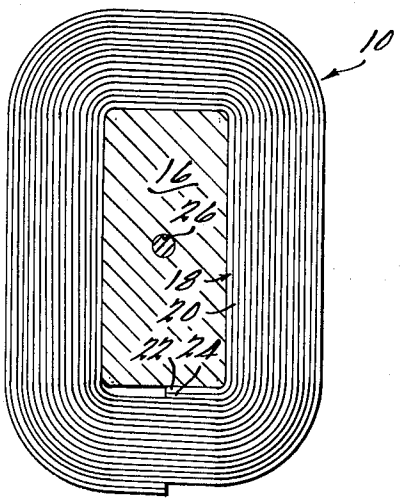



FIG. 2.

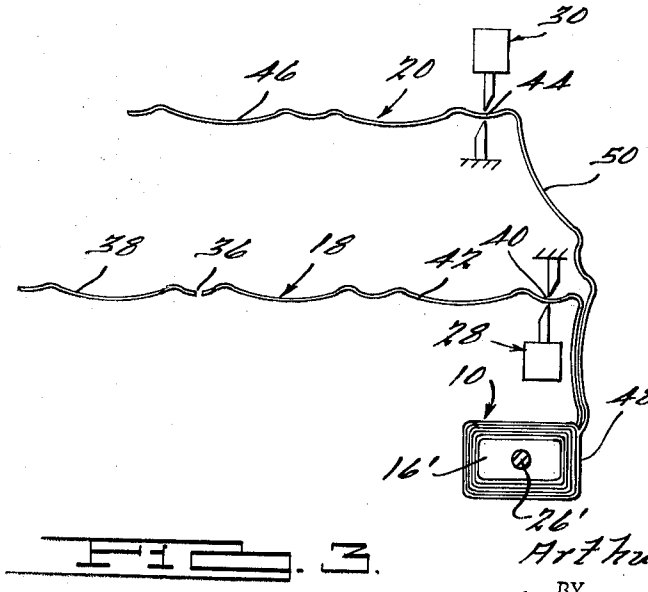



FIG. 3.

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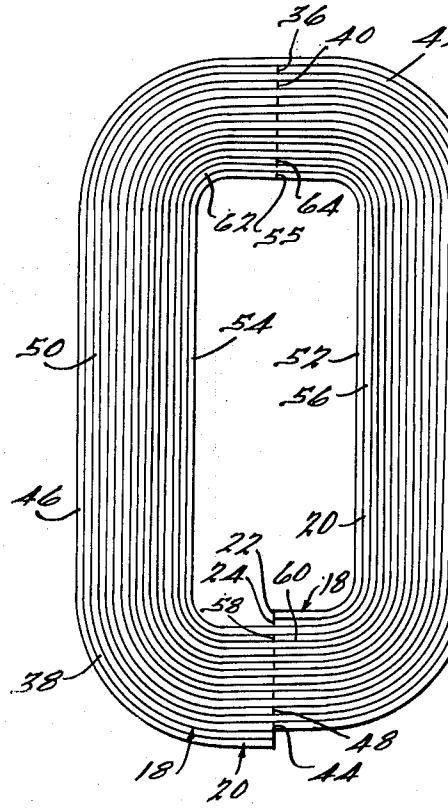



FIG. 4.

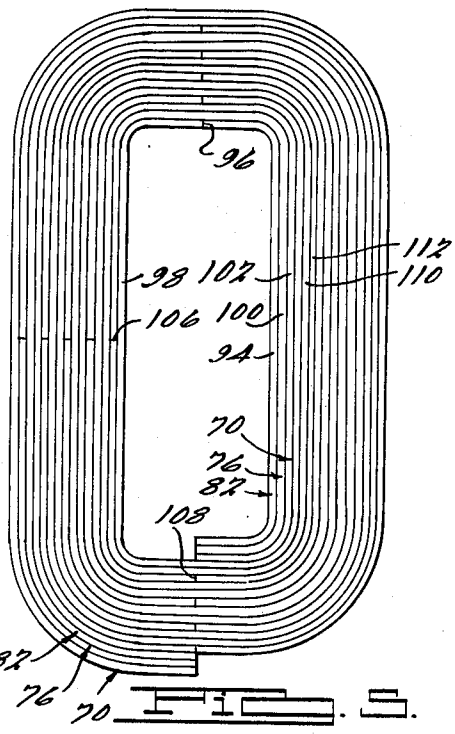



FIG. 5.

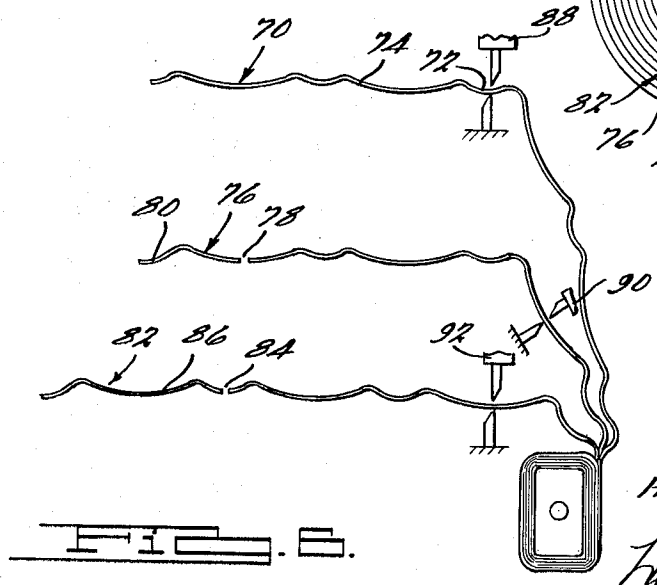



FIG. 6.

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3,252,118

# ELECTROMAGNETIC INDUCTION APPARATUS

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16 Claims. (Cl. 336—213)

This invention relates to electromagnetic induction apparatus and more particularly to an improved wound electromagnetic core for such apparatus.

In the manufacture of certain types of electromagnetic induction apparatus, it has proved to be advantageous to utilize preformed electrical conductive windings and to assemble the core to and upon those windings. It has further proved to be advantageous, particularly in conjunction with preformed windings, to form the core of wound, cold rolled steel strip.

In the general prior practice, a strip of cold rolled steel having a preferred direction of magnetization is wound upon a mandrel to form a spiral, and the wound core is then heat-treated to establish the permanent set of the metal, to relieve the internal strains and to improve the magnetic properties.

In one prior method of assembling the core to the electrical windings, the spiraled strip is rewound, in its entirety, into and on the preformed electrical winding.

To facilitate the assembly operation and to reduce the likelihood that the magnetic properties of the steel will be impaired due to working of the metal during assembly of the core to the conductive winding, it has further been suggested that the core strip be severed, during unwinding, into a plurality of sections, and thereafter assembled section-by-section upon the core, each section being placed in end-abutting relation with the preceding section.

It has been recognized, however, that such sectionalizing of the core tends to impair the magnetic qualities unless pains are taken to insure that the air gaps at the end abutments are adequately bridged by low-reluctance magnetic paths. Accordingly, it has further been suggested that the wound core be formed into sections which are plural turns in length, or that the sections be one or less turns in length, with the joints being staggered. The former method permits all of the sections to be formed into equal (e.g., 2, 2½, 3) turn-lengths and allows appreciable bridging of the butt joints, but requires the manipulation of plural turn-lengths of stock, retarding the speed of assembly and, again, leading to a danger of improper working of the stock subsequent to annealing. The latter method facilitates assembly, but requires that the core sections have substantially differing turn-lengths if the joints are to be staggered to an adequate degree to provide proper bridging or shunting of the air gaps.

The present invention relates to an improved core of the wound type and to an improved method for constructing such cores. By virtue of the improved construction, the core can be formed of relatively short and easily handled sections, most of the sections can be of equal turn-lengths, and adequate bridging can be obtained at each of the end abutments. Further, the cross section of the core legs can be substantially constant.

In accordance with certain of the principles of the present invention, an electromagnetic induction apparatus is provided with an electrical winding structure and a magnetic core structure in linking interrelationship, with the core structure comprising a plurality of wound, pieced, interleaved-spiral magnetic strips. Each turn of each of the plural strips is separated from any other turn of that strip by a turn of at least one other strip, and each strip is formed of a plurality of discrete individual portions, each of those portions being in end-abutting relation with



the next preceding one of those portions. Each of the end abutments is magnetically bridged by a portion of another one of the strips, the distance between any end abutment of one of the spiral strips and the end abutment of the adjacent turn preferably being at least one-quarter of a turn-length so as to insure proper shunting of the high-reluctance air gap with a low-reluctance path. In one embodiment of the invention, most of the end-abutment air gaps are shunted on both sides by portions of another spiraled strip or of other spiraled strips, while in one of the embodiments of the invention, bilateral multilayer bridging is provided, that is, each such end abutment is magnetically bridged by a plurality of portions of other strips on each side.

In the preferred practice, the end abutments of any one of the strips are substantially aligned radially of the core while the end abutments of a second spiraled strip are aligned along another and remotely spaced radius of the core structure. The radial alignment of the end abutments of each strip in this fashion permits the turn-length of the individual core sections to be constant, facilitating both manufacture and assembly.

In order to construct a core embodying the principles of the present invention, a plurality of face-abutting strips of magnetic material are concurrently wound upon an arbor so as to form interleaved spirals in the nature of a bifilar winding. In the preferred procedure, the wound core is then heat-treated. Thereafter the intercoiled strips are unwound, without disturbing the permanent set and the plural strips are severed, as by shearing, at different spaced-apart locations during the unwinding so as to divide each of the strips into a plurality of strip portions. Desirably, but not imperatively, each of substantially all of the sections of each of the spirals is equal in turn-length to the others, so as to facilitate the shearing operation and the subsequent assembly operation. The core can advantageously be fabricated by making the core sections each one turn in length.

Subsequent to the shearing operation, the strips are appropriately stacked and are then assembled upon the electrical winding structure in their original, wound, interleaved spiral relationships. Since but relatively short lengths of stock are assembled to the winding structure, it is simpler to avoid excessive distortion of the strip during its insertion through the electrical winding structure.

A more complete understanding of the core structure, of the method of manufacturing of the core, and of the other principles of the present invention may be obtained from a consideration of the following detailed description of embodiments of the invention when read with reference to the accompanying drawings in which:

FIGURE 1 illustrates a partially completed electromagnetic induction apparatus embodying certain of the principles of the present invention;

FIG. 2 shows the core of the apparatus of FIG. 1 at one stage in its construction;

FIG. 3 illustrates the core of FIG. 2 at a later stage in its construction as well as shearing equipment for severing the core strips into sections;

FIG. 4 is an enlarged view of the assembled core of FIG. 1;

FIG. 5 is a view of a modified form of assembled core; and

FIG. 6 is a view of the core of FIG. 5 at one stage in its construction along with a showing of shearing means for severing each of the plural strips of core material into sections.

In the electromagnetic induction apparatus represented in FIG. 1, a core structure **10** is electromagnetically and mechanically linked with a pair of electrically conductive winding structures **12** and **14** each of which is preformed

prior to association with the core **10**. It is to be understood that the showing of FIG. 1 is merely intended to illustrate one possible relationship between the core structure and the conductive winding structure and that the principles of the invention are applicable to arrangements in which conductive windings are associated with but one leg of the core, in which a plurality of winding means are associated with one or both core legs, and in which one preformed winding structure is common to two cores **10**.

In the arrangement of FIG. 1, the core **10** is formed with a generally rectangular window so as to establish the maximum space factor in relation to the cylindrical (here of generally rectangular cross-section) preformed winding structures.

The core **10** of FIG. 1 comprises a plurality of pieced, interleaved-spiral magnetic strips, two such strips being employed in the embodiment of FIGS. 1 through 4 of the drawings. To construct such a core, two lengths of cold rolled strip steel of appropriate magnetic characteristics, width and thickness (normally about twelve thousandths of an inch) are brought into face-abutting relationship and wound upon a mandrel **16** (FIG. 2). While the mandrel **16** may be stationary and the two face-abutting strips wrapped around the mandrel, the more advantageous procedure is to align and face-abut the two strips **18** and **20**, to secure, in any appropriate fashion, their respective ends **22** and **24** together and to one point upon the surface of the mandrel **16**, and then to rotate the mandrel about the axis of the mandrel shaft **26**, delivering the two strips approximately tangentially to the point of engagement with the mandrel. The incoming strips are or may be normally tensioned to a selected degree (with or without the application of radial pressure at the point of tangency) to provide the requisite tightness and/or shape of core.

It has previously been recognized that in cores which are wound, unwound and assembled to the conductive winding structure, the creepage of the turns of the core from their initial, wound positions during assembly of the core to the conductive winding structure produces misalignment which renders the assembly of the core to its original form very difficult. To provide space to accommodate this creepage, spacers may be disposed between the turns during the winding operation. These spacers can be elements extending but a small portion of the turn-lengths, but it has been found to be preferable to utilize string, fabric or other combustible materials which are coextensive with and lie parallel with the turns. Thus, one or more pieces of string or strips of combustible material can be placed on top of, between, or beneath (or any combination thereof) the two incoming aligned strips of material so that the combustible material is wound concurrently with the steel strips upon the mandrel **16**.

As illustrated, a rectangular mandrel is employed in view of the assumed configuration of the preformed conductive winding means **12** and **14** (FIG. 1). Consequently, each turn is generally rectangular, having four straight leg portions and four right-angle turns, with each such turn being upon a radius.

Subsequent to the winding operation as illustrated in FIG. 2, the core is heat-treated to anneal it and to destroy the combustible spacing material, if such was employed. Thereafter, the wound core is carefully unwound and the component spiraled strips are each severed into a plurality of sections, care being taken during this operation to avoid overstressing the annealed turns of the core. To perform this operation, the shaft **26'** (FIG. 3) of the mandrel **16'** (which may as a matter of manufacturing convenience but need not be the same elements as shaft **26** and mandrel **16** of FIG. 2) is rotatably supported so that the core **10** may be rotated about the axis of that shaft with the two strips of magnetic material **18** and **20** being drawn therefrom. The inner strip **18** is trained through a severing means **28** while the strip **20** constituting the outer spiral is trained through a severing means **30**. Severing means **28** and **30** may be of any suitable well known type and it has been found to be satisfactory, with the subject construction, to employ shearing equipment, obviating the requirement of certain of the prior-art constructions for a sawing operation.

In this connection, it is to be understood that the term "turn-length" is intended to connote the length of any turn of the strip stock of the core, that is, one full turn of the strip even though the actual length of the strip required to complete one full turn will vary between the inner and the outer turn of the core due to the build-up. Similarly, a half turn-length is the length of strip stock required at any point in the build-up to complete 180° of winding of the core and two core lengths is the amount of strip stock, at any point in the build-up, required to complete 720° or two full turns of the core.

In the arrangement illustrated in FIG. 3, strip **18** is first severed at point **36** to form a portion or section **38** one-half turn-length long. Strip **18** is next severed at point **40** so as to produce a portion **42** one turn-length long. Strip **18** is thereafter sheared or otherwise severed each one turn-length. Strip **20** is first sheared at point **44** to form a portion **46** which is one turn-length long and is next sheared at point **48** to form to a portion **50** which is also one turn-length long. Thereafter, strip **20** is cut into one turn-length sections. In the particular structure which is illustrated, the final cut of strip **18** will produce a one-half turn-length innermost section, while the final cut of strip **20** will produce a one turn-length final section.

Following the severing operation, the portions are stacked in succession for convenience in storage and reassembly. Thereafter, the core portions are reassembled in their wound, interleaved spiral relationship about the conductive coil structure. The reassembled core is illustrated (with the conductive winding structure omitted for clarity) in the enlarged view of FIG. 4.

In the assembly of the core **10** to the conductive winding structure, the innermost portion **52** of strip **18** is first placed inside the winding coil structure. The second innermost section **54** of strip **18** is then placed in end-abutting relationship with portion **52**, the end abutment **55** occurring at the top of the core structure in the illustration of FIG. 4. The innermost section **56** of strip **20** is then slipped between core portions **52** and **54**, its innermost end **24** aligning with the innermost end **22** of the strip portion **52**. Portion **56** extends to point **58**, at the bottom leg of the core in the showing of FIG. 4, and the next step in the preferred assembly sequence is to bring section or portion **60** of the strip **20** into abutment with the portion **56** at junction **58**. Thereafter, the next portion **62** of strip **18** is slipped between portions **56** and **60** of strip **20** with the inner end of strip **62** being brought into abutment with the outer end of strip **54** at point **64**.

The building up of the core into its reassembled relationship proceeds in this fashion, terminating with the placing of the outer portion **46** of strip **20** over the outer portion **38** of the strip **18**. The completely assembled core is then secured in position in any suitable, well known fashion.

While the end abutments of the strip **20** including abutments **44**, **48** and **58** are shown to be radially aligned, and while the end abutments of the inner spiraled core strip **18**, including abutments **55**, **64**, **40** and **36** are shown to be aligned along a radius spaced 180° from the line of the abutments of strip **20**, it will be recognized that it is not imperative to the practice of all of the principles of the invention that the abutments of either strip be in alignment or that the 180° spacing be employed. However, as noted hereinbefore, it has been found to be advantageous from a number of standpoints to construct the core in this fashion.

It will be observed in the enlarged showing of FIG. 4 that except for the innermost abutment **55** and the outermost abutment **44**, each end abutment or joint in the structure is bridged on both sides by a strip of magnetic material which extends a very substantial distance in both

directions from the gap so as to insure that a low-reluctance bridge is established. Thus, in the illustrated arrangement, the bridging strips, in each case, are continuous for 180° in both lengthwise directions from the gap.

FIG. 5 of the drawings illustrates a reassembled core structure (with the conductive winding now shown) in which three strips of magnetic steel are utilized to form three interleaved spirals and FIG. 6 shows a step in the construction of the core of FIG. 5. In this modification, three strips of steel are brought into face-abutting relationship and wound upon a mandrel in the manner above discussed in connection with FIG. 2. After annealing, the three interleaved spiral windings are unwound and each strip is severed into a plurality of portions or sections during the unwinding operation, as illustrated in FIG. 6.

In the illustrated arrangement, the outer strip **70** is first severed at the one turn-length point **72** to form the portion **74** and is thereafter sheared each one turn-length. The intermediate strip **76** is first sheared at point **78** to define a one-quarter turn-length portion **80** and is thereafter cut into one turn lengths. The innermost strip **82** is first severed at point **84** to define a one-half turn-length portion **86** and is thereafter severed into one turn-length portions.

In reassembling the strip portions about the conductive winding structure, the innermost portion **94** is first placed within the conductive winding structure, this portion being one-half turn in length and terminating at abutment **96**. Next, portion **98** of strip **82** is placed in end-abutting engagement with portion **94** at abutment **96**. Core elements or portions **100** and **102**, the innermost portions of strips **76** and **70**, respectively, are then slipped between portions **94** and **98**, their innermost ends being aligned with the innermost end of section **94**. It will be observed that core portion **100** is three-quarters of a turn-length long (270°) and hence terminates along the left-hand vertical leg of the core at junction **106** and that portion **102** is one turn-length long (360°) and hence terminates at junction **108** along the bottom leg of the core.

Portion **110** of strip **82** is then placed in end-abutting relationship, at **106**, with portion **100**, and portion **112** of strip **76** is placed in end-abutting relationship, at **108**, with portion **102**. Succeeding strip portions are assembled in this fashion to complete the core.

In the core of FIG. 5, it will be observed that except for the innermost and outermost end abutments, each of the end abutments is bridged on both sides by a multiple layer of metal strip, each of the end junctions being representatively bridged by two layers of the strip steel at each side. Further, the bridging steel does not, in the disclosed arrangement, itself have a junction for at least 90° so that an excellent low-reluctance bridging or shunting path is provided for each of the air gaps which tend to exist at the end abutments, still further improving the magnetizing current characteristics in the vicinity of the joints.

The principles of the construction can be extended to four, five or $n$ interleaved spiral strips. If the preferred practice above described is followed, the gaps in the four, five or $n$ spiral paths will appear at four, five or $n$ points along the magnetic path.

It is reiterated that it is not imperative to the practice of the principles of the invention that the end abutments in any one of the strips be aligned but that they may be staggered if desired, and it should further be noted that each of the strips illustrated in FIGS. 4 and 5 of the drawings may, if desired, actually be made up of plural component strip thicknesses. In that event, it is also not imperative that an equal number of metal thicknesses be employed to form each of the strips, that is, the number of constituent elements forming one of the spirals may be different than the number of metal thicknesses constituting another one of the spirals.

It will also be observed that the principle of concurrently winding a plurality of strips in interleaved spirals can also be applied to the manufacture of cores in which the strips are not pieced, possessing the advantage that the length of the material, with $n$ interleaved spiral strips of a given thickness, which would have to be threaded through the winding structure to obtain a desired core thickness would be $1/n$ of the total length which would be required if the entire core were formed of a single strip of the same thickness, as in the prior practice.

While it will be apparent that the embodiments of the invention herein disclosed are well calculated to fulfill the objects of the invention, it will be appreciated that the invention is susceptible to modification, variation and change without departing from the proper scope or fair meaning of the subjoined claims.

What is claimed is:

**1.** Electromagnetic induction apparatus comprising an electrical winding structure and a magnetic core structure in linking interrelationship, said core structure comprising a plurality of wound, pieced, interleaved-spiral magnetic strips.

**2.** Electromagnetic induction apparatus comprising an electrical winding structure and a magnetic core structure in linking interrelationship, said core structure comprising a plurality of pieced, interleaved-spiral magnetic strips, each turn of each of said strips being separated from any other turn of said strip by a turn of at least one other strip.

**3.** Electromagnetic induction apparatus comprising an electrical winding structure and a magnetic core structure in linking interrelationship, said core structure comprising a plurality of wound, pieced, interleaved-spiral magnetic strips, each of said strips being formed of a plurality of discrete individual portions, each of said portions of any one strip end-abutting another one of said portions of said any one strip.

**4.** The combination of claim **3** in which most of said portions are one turn in length.

**5.** Electromagnetic induction apparatus comprising an electrical winding structure and a magnetic core structure in linking interrelationship, said core structure comprising a plurality of wound, pieced, interleaved-spiral magnetic strips, each of said strips being formed of a plurality of discrete individual portions in successive end-abutting relationship, most of said end abutments being bridged by portions of another one of said strips.

**6.** Electromagnetic induction apparatus comprising an electrical winding structure and a magnetic core structure in linking interrelationship, said core structure comprising a plurality of wound, pieced, interleaved-spiral magnetic strips, each of said strips being formed of a plurality of discrete individual portions in successive end-abutting relationship, each of said end abutments being bridged by a portion of another one of said strips.

**7.** Electromagnetic induction apparatus comprising an electrical winding structure and a magnetic core structure in linking interrelationship, said core structure comprising a plurality of wound, pieced, interleaved-spiral magnetic strips, each of said strips being formed of a plurality of discrete individual portions in successive end-abutting relationship, each of said end abutments being bridged on both sides by portions of another one of said strips.

**8.** Electromagnetic induction apparatus comprising an electrical winding structure and a magnetic core structure in linking interrelationship, said core structure comprising a plurality of wound, pieced, interleaved-spiral magnetic strips, each of said strips being formed of a plurality of discrete individual portions in successive end-abutting relationship, each of said end abutments being bridged by multiple layers of magnetic strip.

**9.** Electromagnetic induction apparatus comprising an electrical winding structure and a magnetic core structure in linking interrelationship, said core structure com-

prising a plurality of wound, pieced, interleaved-spiral magnetic strips, each of said strips being formed of a plurality of discrete individual portions in successive end-abutting relationship, each of said end abutments being bridged on both sides by multiple layers of magnetic strip.

**10.** Electromagnetic induction appartus comprising an electrical winding structure and a magnetic core structure in linking interrelationship, said core structure comprising a plurality of wound, pieced, interleaved-spiral magnetic strips, each of said strips being formed of a plurality of discrete individual portions in successive end-abutting relationship, each of said end abutments being bridged on each side by portions of two other ones of said strips.

**11.** The combination of claim **10** in which most of said portions are one turn in length and in which the end abutments of any one of said strips are substantially aligned radially of the core.

**12.** The combination of claim **10** in which the end abutments of one of said strips are circumferentially spaced about said core structure from the end abutments of another one of said strips.

**13.** The combination of claim **12** further characterized in that the end abutments of said one strip are aligned radially of said core structure and in that the end abutments of said other strip are aligned along another radius of said core structure.

**14.** Electromagnetic induction apparatus comprising an electrical winding structure and a magnetic core structure in linking interrelationship, said core structure comprising a plurality of wound, pieced, interleaved-spiral magnetic strips, each of said strips being formed of a plurality of discrete individual portions in successive end-abutting relationship, each of said end abutments being bridged on both sides by portions of another one of said strips, most of said portions being one turn in length.



**15.** Electromagnetic induction apparatus comprising an electrical winding structure and a magnetic core structure in linking interrelationship, said core structure comprising a plurality of wound, pieced, interleaved-spiral magnetic strips, each of said strips being formed of a plurality of discrete individual portions in successive end-abutting relationship, each of said one abutments being bridged by multiple layers of magnetic strip, most of said portions being one turn in length.

**16.** The combination of claim **12** further characterized in that the end abutments of said one strip are aligned radially of said core structure and in that the end abutments of said other strip are aligned along another radius of said core structure, most of said portions being one turn in length.


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