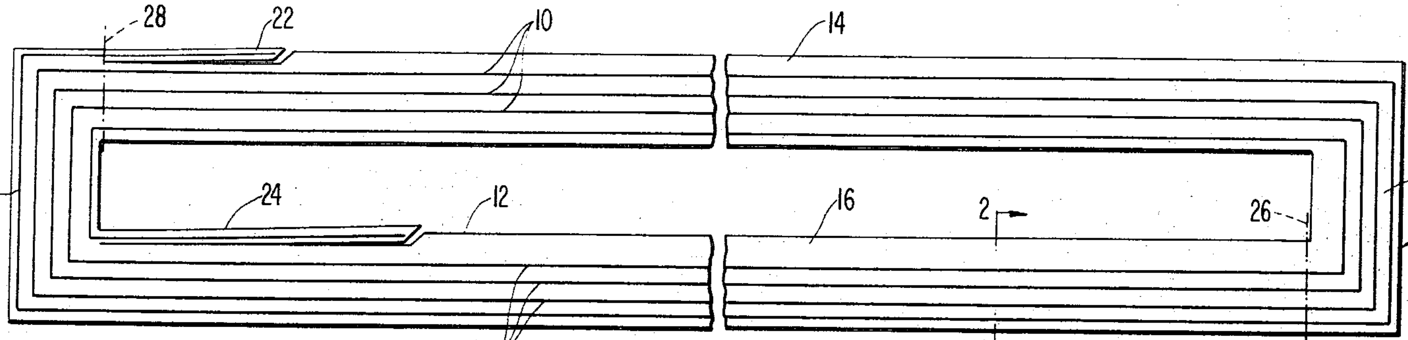
Feb. 2, 1971
D. F. WILKES
3,560,904
ELECTRIC COILS
Filed April 19, 1968
3 Sheets-Sheet 1

FIG. 1



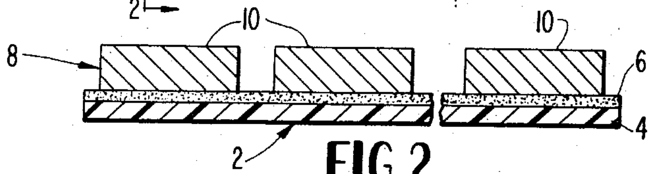


FIG. 2

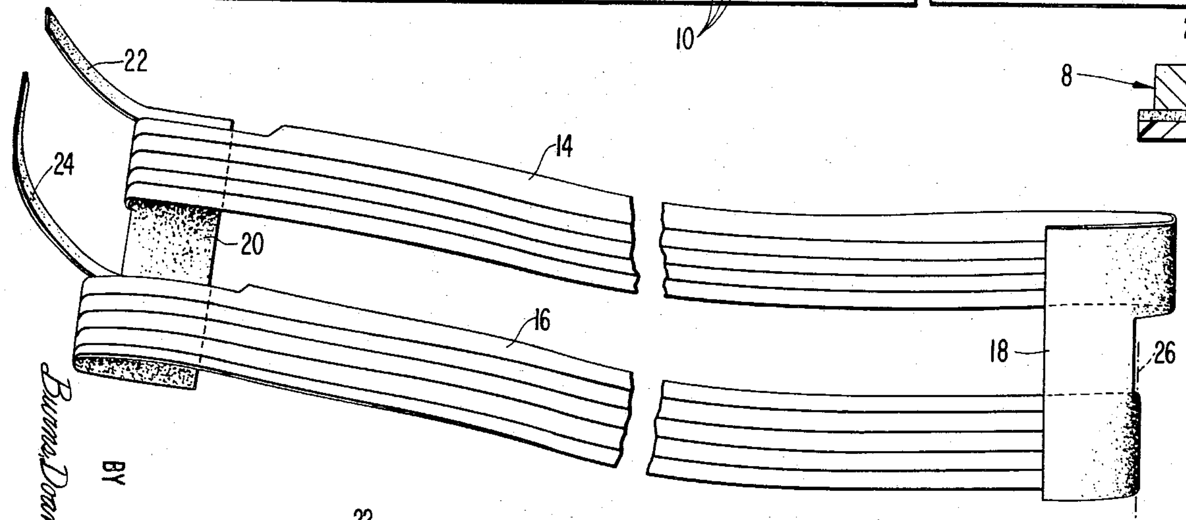


FIG. 3

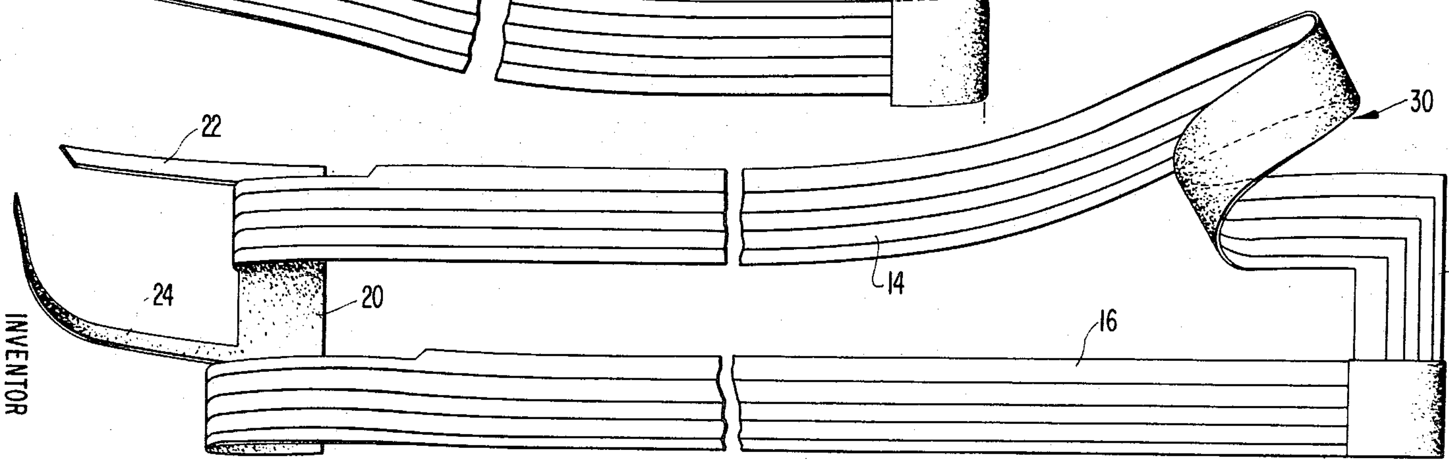


FIG. 4

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ELECTRIC COILS

Filed April 19, 1968 3 Sheets-Sheet 2

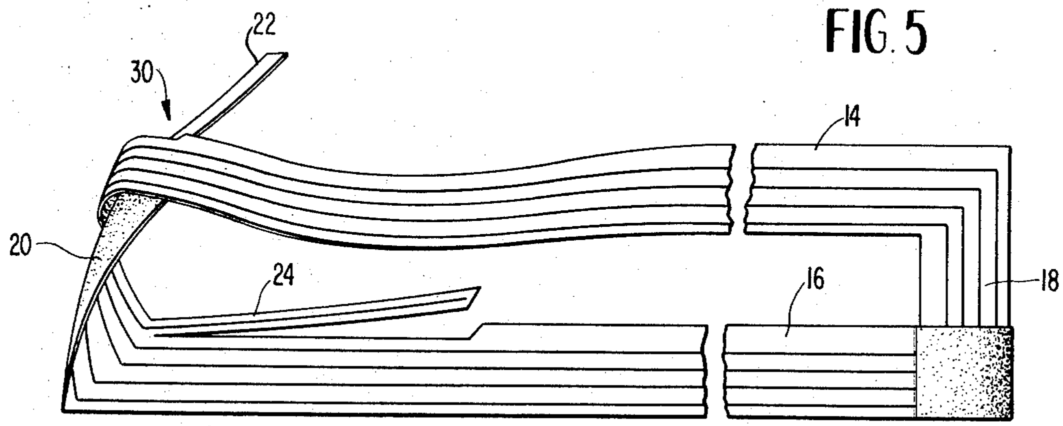

FIG. 5

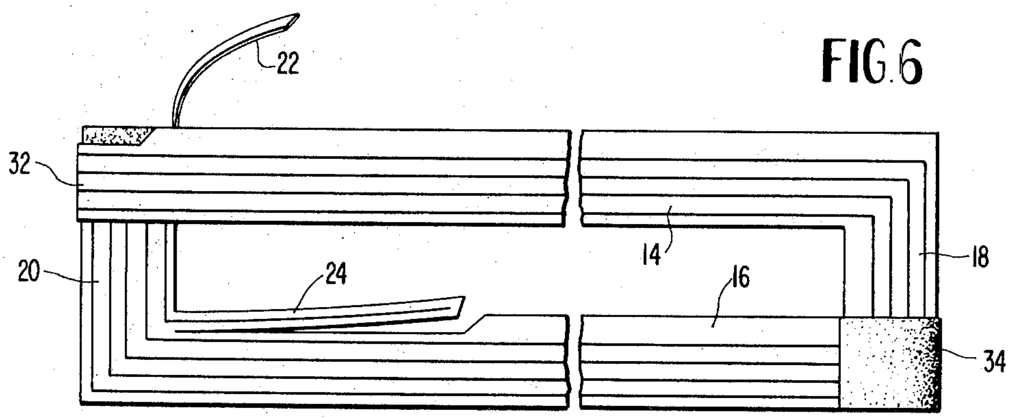

FIG. 6

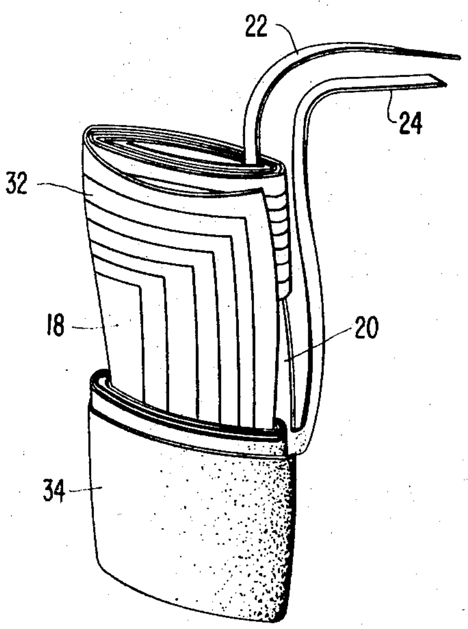

FIG. 7

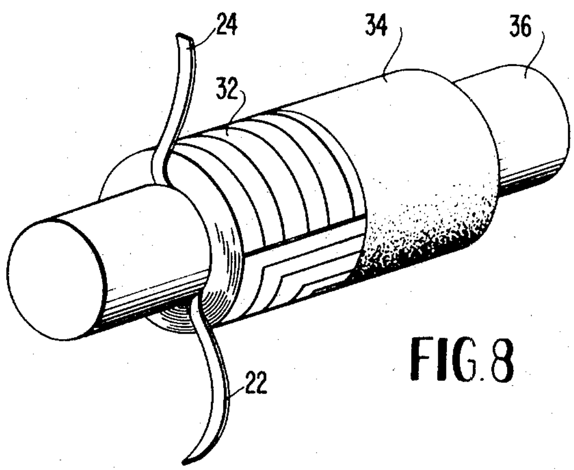

FIG. 8

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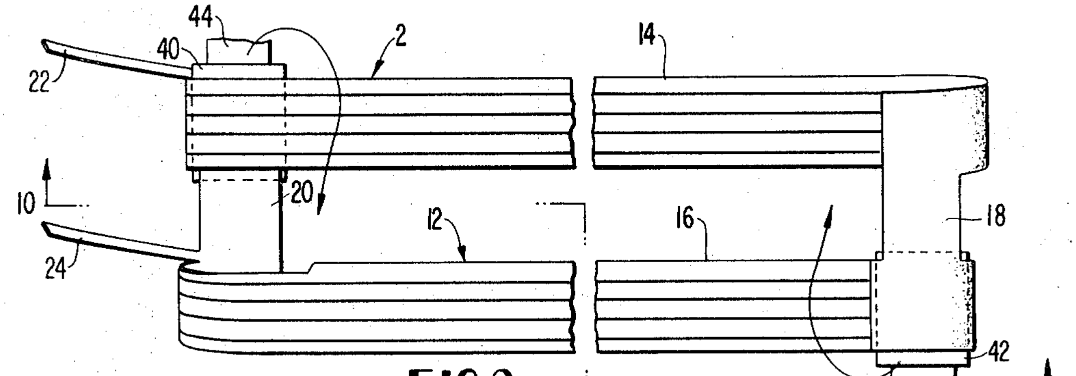

FIG. 9

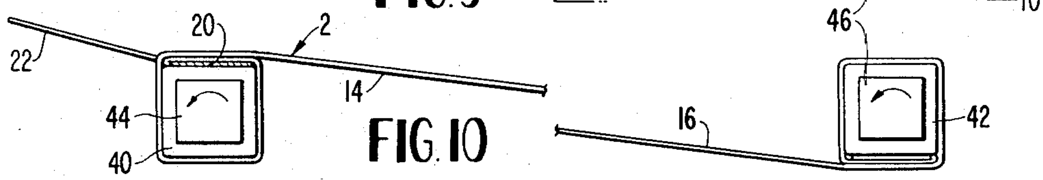

FIG. 10

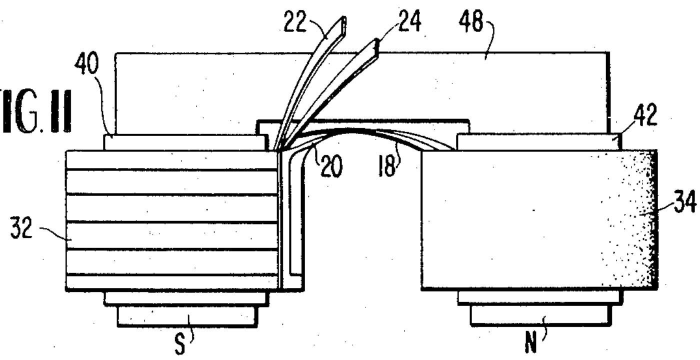

FIG. 11

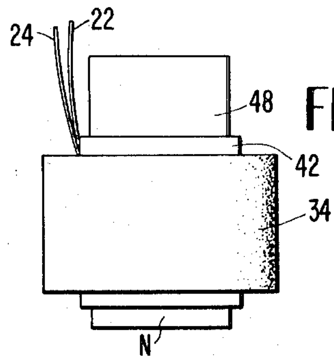

FIG. 12

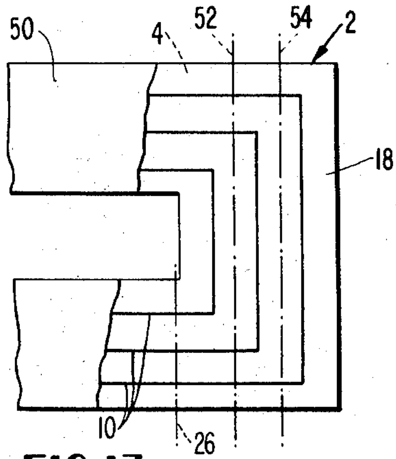

FIG. 13

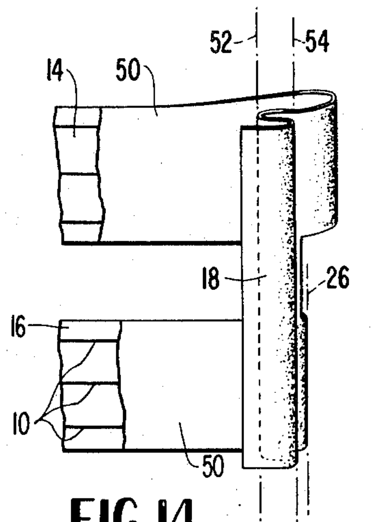

FIG. 14

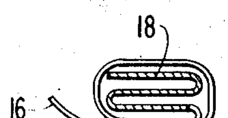

FIG. 15

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3,560,904

ELECTRIC COILS

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Int. Cl. H01f *27/28, 41/04*
U.S. Cl. 336—180 14 Claims

ABSTRACT OF THE DISCLOSURE

An electric coil in which the turns of the conductor are wound in multiples, rather than in single strands. The conductor is printed or otherwise provided on a web of insulating material. The conductor is arranged in a spiral pattern around a central opening in the web. The web on opposite sides of the opening is wound in opposite directions so that the flux produced by current in the conductor is additive when the windings have a common central axis.

BACKGROUND OF THE INVENTION

This invention relates to electric coils, and more particularly to coil structures and methods for producing coils.

Electric coils are usually made by wrapping insulated magnet wire around a coil form either in a regular traversing pattern or in a random fashion to produce the finished coil. Thus, the turns of the coil are wound sequentially.

When the magnet wire is wound on a coil, the length of wire required is usually very great. Often as much as several thousand feet of wire are used in winding a coil. Winding the coil with this length of wire is necessarily slow and the process must be accurately controlled to produce the desired coil form. Magnet wire has a circular cross section and is covered by insulation. Due to the crevices that necessarily remain between adjacent turns of wire, the volume of the coil is substantially greater than the total volume of wire and insulation in the coil.

Heat transfer in this kind of coil is poor due to the long average length of conductor from the coil interior to the outer heat conductive radiating surface. Transverse heat transfer is greatly hampered by the multitude of layers of insulating material and the interspersed gaps between the wires.

Conventional coils utilize coil forms on which the wire is wound. The coil forms are used during the winding process and serve as insulation between the coil and the core or armature. These coil forms also strengthen the coil. There are, however, disadvantages in using these coil forms. The coil forms necessarily take up the space between the core and the coil. It is desirable for the coils to be placed as close as possible to the armature or core, since the electromagnetic coupling to the core is most efficient in the area immediately surrounding the core.

One difficult problem with conventional wire wound coils is that external leads that carry current from the power source to the coil must be attached after the coil has been wound. The attachment of the leads is usually done by hand after carefully stripping the insulation from the wire. The coil wire itself cannot be used for the external leads because it is single strand wire and breaks easily when flexed.

In view of these defects of conventional wire wound coils, it is an object of this invention to provide improved electric coil structures.

Another object is to provide a rapid and efficient method of winding coils.

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A further object of this invention is to provide a coil structure having a minimum volume.

A still further object of this invention is to provide a coil structure that does not require a coil form and which makes the attachment of separate lead wires unnecessary.

SUMMARY OF THE INVENTION

These objects are accomplished in accordance with a preferred embodiment of the invention by a thin flat web of insulating material having a conductor formed integrally with the insulating web. The web has a longitudinal slot which divides the web into substantially parallel elongated bands and cross links are provided in the web at opposite ends of the slot. The conductor is arranged in a spiral pattern around the slot. The conductor extends along both bands and across each cross link to form a continuous electric path from the outer perimeter of the web to the edge of the slot. One band is wrapped around one of the cross links and the other band is wrapped around the other cross link in the opposite direction. The web material insulates one turn of the conductor from the next turn on each of the coils that are wound on the respective cross links. When the winding operation is completed, there are an equal number of turns of the band on each cross link, and the cross links are positioned on opposite sides of the pairs of coils formed by the bands. Integral leads from the conductor are separated from the web and a core or armature is inserted through the center of each of the pair of coils.

DETAILED DESCRIPTION OF THE DRAWINGS

This preferred embodiment of the invention is illustrated in the accompanying drawings in which:

FIG. 1 is a top plan view of the coil winding sheet of this invention;

FIG. 2 is an enlarged cross sectional view of the sheet along the line **2—2** in FIG. 1;

FIG. 3 is a top plan view of the sheet showing the initial step in winding the bands on the cross links;

FIG. 4 is a top plan view of the coil winding sheet after turning one band on one of the cross links;

FIG. 5 is a top plan view of the coil winding sheet showing the step of winding one of the bands on the opposite cross link;

FIG. 6 is a top plan view of the sheet showing the bands partially wound on the cross links;

FIG. 7 is a side elevational view of the coil winding sheet after the winding operation is completed;

FIG. 8 is a perspective view of the completed coil, with a core or armature;

FIG. 9 is a top plan view of the coil winding sheet being wound with mandrels;

FIG. 10 is a cross sectional view of the sheet along the line **10—10** in FIG. 9;

FIG. 11 is a side elevational view of a magnet with the coils mounted on a U-shaped core;

FIG. 12 is an end elevational view of the magnet of FIG. 11;

FIG. 13 is a top plan view of the coil winding sheet prior to folding the cross link;

FIG. 14 is a top plan view of the sheet of FIG. 13 after folding; and

FIG. 15 is a cross sectional view of the cross link after folding.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, the coil winding sheet **2** of this invention includes a flexible web **4** of insulating material, such as "Mylar" polyester film. The web **4** preferably has a thickness in the range of from .0005 to .003 inch.

As shown in FIG. 2, an adhesive layer 6 is superimposed on the front face of the web 4. The adhesive layer 6 preferably has a thickness of about .00005 inch. The adhesive layer 6 bonds a conductive layer 8 to the insulating web 4. The conductive layer is formed of copper, aluminum, a copper alloy or other electrically conductive material. The layer 8 preferably has a thickness in the range between .0003 and .002 inch. The combined thickness of the web 4, the adhesive layer 6 and the conductive layer 8 should be sufficiently small to allow adequate flexing and bending of the sheet 2. If adequate bonding of the conductive layer 8 directly to the web can be achieved, the adhesive layer 6 may be eliminated, thereby reducing the thickness of the sheet.

The conductive layer 8 is applied as a continuous sheet and subsequently portions of the sheet area are removed by chemical etching or other conventional processes to form a continuous conductor 10. Adjacent portions of the conductor 10 are separated by air gaps and are insulated from each other by the adhesive layer 6 and the web 4. Of course, as an alternative any suitable process may be utilized for applying the conductor 10 to the surface of the insulating web 4. For example, the adhesive layer 6 may be a thermosetting adhesive. The conductive layer 8 is then applied to the thermosetting layer 6 and bonded by a partial heat set. The conductive layer 8 is then chemically etched to produce the conductor 10. Subsequently, the sheet is placed in a press and the conductor 10 is pressed against the thermosetting layer to displace the adhesive upwardly into the spaces between adjacent portions of the conductor 10. The sheet is then heated to cure the adhesive. Thus, the adhesive acts not only as a bonding agent, but also insulates adjacent portions of the conductor from each other.

The web has an elongated slot 12 extending longitudinally thereof and dividing the web 4 into a pair of elongated parallel bands 14 and 16 and cross links 18 and 20 at opposite ends of the slot 12. The conductor 10 extends from the outer peripheral edge of the web 4 in a spiral pattern to the edge of the slot 12, as shown schematically in FIG. 1. A portion of the web 4 adjacent the outer end of the conductor 10 is severed to form a lead 22. Similarly, the inner end of the conductor 10 is separated from the web 4 by a slot in the sheet to form a lead 24.

The conductor 10 extends from the outer lead 22 along the cross link 20, longitudinally of the band 16, along the cross link 18, and longitudinally of the band 14 in a spiral pattern. A plurality of spirals are provided on the sheet 2 between the outer and inner leads 22 and 24, respectively. The several spirals of the conductor 10 as illustrated in FIG. 1 are merely exemplary of the number and spacing of spirals that might be provided. In actual practice, several hundred spirals per inch of width of the band 14 or 16 can be provided.

If an electric potential is applied across the leads 22 and 24 to cause current to flow from the lead 22 to the lead 24, it is apparent from tracing the spiral conductor pattern that current flows in the band 14 from the right hand to end to the left hand end as viewed in FIG. 1, while current flows from the left hand end of the band 16 to the right hand end of the band. Thus, current is flowing in opposite directions in the conductors on the bands 14 and 16.

The sheet 2 constitutes the coil winding of this invention. The coil is wound by first folding the cross link 18 about an axis 26 extending transversely of the band 16, as shown in FIGS. 1 and 3. The sheet 2 has a sharp bend along the axis 26 and the conductor 10 on the band 16 engages the conductor 10 on the cross link 18. At the opposite end of the cross link 18, the band 14 is rolled without creasing. The opposite cross link 20 is folded along an axis 28 with the front face of the web 4 on which the conductor 10 is applied being exposed after the fold has taken place. This fold causes the lead 22 to project

outwardly, as shown in FIG. 3. At the opposite end of the cross link 20, the band 16 is rolled without creasing.

The next step in the coil winding procedure is to rotate the cross link 18 about its left hand edge as viewed in FIG. 3, until the rear face of the web 4 engages the conductor 10 on the band 16. The opposite cross link 20 remains in the positions shown in FIG. 3 during this rolling of the cross link 18. When the cross link 18 has been rolled in this manner, a loop 30 is formed in the band 14. The loop 30 is wrapped on the cross link 20 by rotating the band 14 approximately about its longitudinal axis, while allowing the cross link 20 to flex as necessary, as shown in FIG. 5.

After the loop 30 has been applied to the cross link 20, the sheet 2 returns to its generally flat configuration, as shown in FIG. 6, with one winding of the band 14 on the cross link 20 and one winding of the band 16 on the cross link 18. The band 14 produces a winding 32 on the cross link 20 with the rear face of the web 4 on the inside of the winding, while the band 16 produces a winding 34 on the cross link 18, with the rear face of the web 4 on the outside of the winding.

The winding steps illustrated in FIGS. 4, 5 and 6 are repeated sequentially until substantially the entire length of the bands 14 and 16 are wound on the respective cross links 18 and 20. The sheet 2 then has generally the shape shown in FIG. 7, with the cross links 18 and 20 extending from the interior of one winding to the exterior of the other winding. The windings 32 and 34 are formed into a rounded shape and the center of each winding is opened to allow the insertion of a core or armature 36, as shown in FIG. 8. The core 36 has an insulating coating to avoid shorting out the exposed conductor 10. The leads 22 and 24 are arranged at one end of the coil winding for attachment to a source of electricity.

Since the conductor in the windings 32 and 34 turns in opposite directions, the current flows in the same direction in both windings around the circumference of the core 36. Consequently, the flux induced in the core 36 by the windings is additive.

It is contemplated that the conductor 10 has a large number of spirals closely spaced together so that a great number of turns are produced in each winding. For example, the conductor 10 may have a width of .002 inch and the space between adjacent portions of the conductor may be .001 inch. With this spacing, approximately 333 turns per inch of width of the band are provided. If the total thickness of the sheet 2 is .003 inch, then a density of 333 spiral wraps per inch of radial thickness of the windings can be achieved. Since there are two bands, a single wrap produces 666 turns of the conductor for each inch of length of the coil.

By applying the conductor 10 on the web 4, structural integrity for the windings is achieved. This characteristic is not exhibited by a conventional coil that is wound with a single magnet wire. Furthermore, by utilizing conductors of rectangular cross section, as shown in FIG. 2, a maximum area of the conductor is presented. The use of an insulating web 4 with a layer of adhesive minimizes the danger of shorting of the coil due to pin holes in the insulation. Another advantage of the rectangular cross section is that the coil formed in this manner may be extremely flexible, if that is desirable. The completed coil, however, is very stiff and resists bending laterally, so that there is a controlled amount of flexibility.

The leads 22 and 24 are integral wtih the sheet 2 and therefore are more readily attached to external leads or other means for connecting the coil in a circuit. If a more stiff lead is desired, the free end of the lead may be doubled over with the conductor being exposed on the outside of the lead.

An alternate method of winding the coils from the sheet 2 is illustrated in FIGS. 9 and 10. Although the coils may be wound without a coil form, the band 14 is shown as being wrapped or wound on a tubular form 40 having a square cross section. The band **16** is also wound on a tubular form **42** having a square cross section. The forms may be circular or rectangular, or any other suitable shape in cross section. The forms **40** and **42** are mounted on mandrels **44** and **46**, respectively. The mandrels **44** and **46** are inserted in the respective forms, but when the coils are to be wound without forms, the sheet **2** may be wound directly on the mandrels **44** and **46**. Of course, the mandrel would then have the appropriate cross sectional shape for obtaining a coil of the desired configuration.

The cross link **20** of the sheet **2** is folded back along the fold line **28** (FIG. 1), and applied to the upper face of the form **40**. Similarly, the cross ling **18** is folded over the band **16** along the fold line **26** and applied to the lower surface of the form **42**, as shown in FIG. 10. The mandrels **44** and **46** are both rotated counterclockwise, as viewed in FIG. 10, thereby generating loops corresponding to the loop **30** illustrated in FIG. 4. The loops are formed in both of the bands **14** and **16**, and these loops are wrapped on the respective cross links **18** and **20** by rotating the mandrel and the coil that is wound on the mandrel through the central opening **12** in the direction of the arrows in FIG. 9. This movement of the mandrels causes the bands **14** and **16** to untwist about their longitudinal axis and consequently the loops are removed.

The resulting coils **32** and **34** may then be removed from the mandrel **44** and **46**, respectively. The coils may be mounted on a U-shaped ferromagnetic core **48** to form an electromagnet. The leads **22** and **24** are the only connection required for energizing both of the coils **32** and **34**. By connecting a source of electric current to the leads **22** and **24**, the coils **32** and **34** are energized simultaneously, with the direction of current inducing magnetic flux in the core **48**, with a south pole S and a north pole N. Cores of other appropriate shapes may also be utilized in connection with the coils **32** and **34** to produce electromagnets having the desired external shape.

One advantage of winding the coils **32** and **34** on the mandrels **44** and **46** or on the forms **40** and **42** is that the bands **14** and **16** may be wound tightly and remain undisturbed during subsequent assembly of the coil on a core. The metallic conductor **10** is subjected to cold working due to bending during the winding process. If it is necessary also to shape the coil after winding, the additional cold working may cause a significant change in resistance of the conductor. Therefore, it is desirable to minimize cold working, and this is done by using the mandrel or form during winding of the coil.

The oppositely wound coils compensate for the effects of cold working. Since the band **14** is wound on the form **40** with the conductor on the outside, while the band **16** is wound on the form **42** with the conductor facing toward the center of the coil, changes in resistance due to stretching and compression of the conductor are substantially equalized. Stretching of the conductor tends to increase its resistance, while compression of the conductor tends to decrease its resistance. Since the number of turns of the bands **14** and **16** is approximately the same in both coils, the stretching of the conductor in the band **14** is approximately equal to the linear compression of the conductor that takes place in the band **16**. Therefore, the change in resistance tends to cancel out.

Referring to FIGS. 13 to 15, the sheet **2** may have a thin flexible insulating film **50** applied over the entire upper face of the sheet **2** covering the conductor **10**. The layer **50** not only serves to insulate the conductor portions in the cross links **18** and **20** from the conductor portions in the bands **14** and **16**, but also serves to insulate the exposed conductor in the completed coil **32**.

The width of the cross links **18** and **20** may be substantially reduced by folding the links transversely. In FIGS. 13 to 15, the link **18** is pleated or folded along fold lines **52** and **54**. In order to avoid shorting out the spirals of the conductor **10** when the cross link **18** is

folded, an insulating layer should be applied over the conductor **10** and the layer **50** can conveniently serve this purpose. Although there are only two fold lines shown in FIGS. 13 and 14, a greater number or a lesser number of folds may be utilized as necessary to reduce the width of the cross link **18**. When the cross link **18** has been folded, the band **16** may be tightly wound on the cross link, as shown in FIG. 15. The pleating or folding of the cross links is particularly useful in winding small coils.

Although there are advantages in winding the bands **14** and **16** in opposite directions, it may also be possible to utilize a pair of coils wound merely by rolling one end of the sheet **2** toward the other. In the resulting pair of coils, the conductor is coiled in the same direction and thus current would induce magnetic flux in opposite axial directions in the coils. However, if the coils are displaced out of axial alignment, such as being placed side by side on a core, as in FIG. 11, corresponding ends of the coils would have the same magnetic polarity. Also, if the cross links **18** and **20** are sufficiently long, one of the coils may be turned end for end and positioned in axial alignment with the other coil. The induced magnetic flux in both coils would then be in the same axial direction and would be additive. The sheet **2** therefore may be utilized to produce coils in which the conductor is wrapped either in the same or in opposite directions, and both coils are energized by the common conductor.

The heat conduction in the coil of this invention is greatly improved over conventional wire wound coils. Heat may be conducted along the length of the conductors to the outer surface of the coil, which for the same number of turns is a shorter distance due to the parallel arrangement of the conductors.

The coil of this invention also permits the windings to be separated into a plurality of coils such as are required in transformers. For example, there may be four equal coil sets by tapping appropriate spirals of the conductor. The four coils, if connected in series, would have four times the resistance of a single coil, and by various parallel or series combinations of the four coils, a great variety of resistances can be achieved.

While this invention has been illustrated and described in a preferred embodiment, it is recognized that variations and changes may be made therein without departing from the invention as set forth in the claims.

I claim:

1. A coil winding comprising:

a thin flexible elongated web of insulating material having a front face and a rear face, said web including a pair of bands joined together at opposite ends by cross links,

electric current conducting means on said bands and extending between said opposite ends, said current conducting means including a plurality of current conducting paths on each band,

electric terminal means at opposite ends of said current conducting means, said conducting means causing current to flow longitudinally along said paths on one band in one direction and along said paths on the other band in the opposite direction when electric potential is applied across said terminal means,

said one band being wrapped in a coil around one cross link with the front face of said one band being on the inside of said coil, said other band being wrapped in a coil around the other cross link with the rear face of said other band being on the inside of said coil, whereby current flowing in said paths induces flux in the same direction at the center of both coils.

2. A coil winding comprising:

a flexible elongated web of insulating material having a front face and a rear face, said web having a longitudinal slot therein dividing said web into opposite end portions and a pair of elongated bands extending from one end portion to the other, said web having a conductor thereon, said conductor having one end adjacent the outer peripheral edge of said web and the opposite end adjacent the edge of said slot,

said conductor extending progressively along one band, one end portion, the other band and the other end portion in a spiral, said conductor being arranged in a plurality of said spirals and being continuous between said conductor ends,

said one band being wound around said one web end portion and the other band being wound around said other web end portion to form a pair of coils joined together by said web end portions, each coil having a plurality of web layers insulating said conductor,

the front web face of said one band being turned toward the central axis of its coil and the rear web face of said other band being turned toward the central axis of its coil, whereby current flowing in said conductor generates magnetic flux in the same axial direction in both coils.

3. A coil winding according to claim **2** wherein said conductor extends along each of said bands and transversely across said end portions in a spiral pattern.

4. A coil winding according to claim **2** wherein said conductor has one end adjacent said web outer edge and has the opposite end adjacent said slot.

5. A coil winding according to claim **2** wherein said conductor is integral with said web and projects outwardly from said front face, adjacent portions of said conductor being spaced apart laterally.

6. A coil winding according to claim **2** including a common core extending through the center of both coils.

7. A coil winding according to claim **2** wherein said central axis of one coil is parallel to the central axis of the other coil.

8. A coil winding according to claim **2** wherein said central axis of one coil is aligned with the central axis of the other coil.

9. A coil winding comprising:

a flexible elongated web of insulating material having a front face and a rear face, said web having a longitudinal slot therein dividing said web into opposite end portions and a pair of elongated bands extending from one end portion to the other,

said web having a conductor thereon, said conductor having one end adjacent the outer peripheral edge of said web and the opposite end adjacent the edge of said slot,

said conductor extending progressively along one band, one end portion, the other band and the other end portion in a spiral, said conductor being arranged in a plurality of said spirals and being continuous between said conductor ends, each of said end portions and each of said bands being traversed by the same number of conductor spirals,

said bands being wound in opposite directions around one of said end portions to form a pair of coils joined together by said web end portions, each coil having a plurality of web layers insulating said conductor, whereby current flowing in said conductor in an opposite direction in each band generates magnetic flux in the same axial direction in said coils.

10. A method of winding a coil from a flexible elongated web of insulating material having a longitudinal slot therein dividing said web into opposite end portions and a pair of bands extending from one end portion to the other and having a conductor thereon, said conductor having one end adjacent the outer peripheral edge of said web and the opposite end adjacent the edge of said slot, said conductor extending progressively along one band,

one end portion, the other band and the other end portion in a spiral, said conductor being arranged in a plurality of said spirals and being continuous between said conductor ends, said web having a front face and a rear face, said method comprising:

folding one end portion in overlapping relation with said one band front face and folding the other end portion in overlapping relation with said other band rear face,

winding said one band in a coil about said one end portion thereby forming a twisted loop in said other band, and

wrapping said loop around said other end portion,

whereby an equal number of turns are wound on each end portion and the bands are wound in opposite directions to generate magnetic flux in the same axial direction by both of said bands.

11. A method of winding a coil according to claim **10** including the additional step of winding said other band in a coil about said other end portion thereby forming a loop in said one band, and rotating said band coils about the lengthwise dimension of the respective bands to untwist said bands, whereby loops in both bands are wrapped around their respective end portions.

12. A method of winding a coil according to claim **11** wherein said winding step is performed on both bands simultaneously and said rotating step is performed on both bands simultaneously.

13. A method of winding a coil comprising:

applying a conductor to a flexible elongated web of insulating material having a longitudinal slot therein dividing said web into opposite end portions and a pair of elongated bands extending from one end portion to the other,

folding one end portion in overlapping relation with said one band front face and folding the other end portion in overlapping relation with said other band rear face,

winding said one band in a coil about said one end portion thereby forming a loop in said other band and winding said other band in a coil about said other end portion thereby forming a loop in said one band, and

rotating said band coils about the lengthwise dimension of the respective bands to untwist said bands, whereby said loops are wrapped around their respective end portions and said conductor on said bands being wound in opposite directions to produce additive electromagnetic effects.

14. A method of winding a coil according to claim **13** including pleating said end portions before winding said bands.

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THOMAS J. KOZMA, Primary Examiner

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