SPACER FOR PANCAKE COILS

Original Filed May 21, 1962 3 Sheets-Sheet 1

Fig. 1A

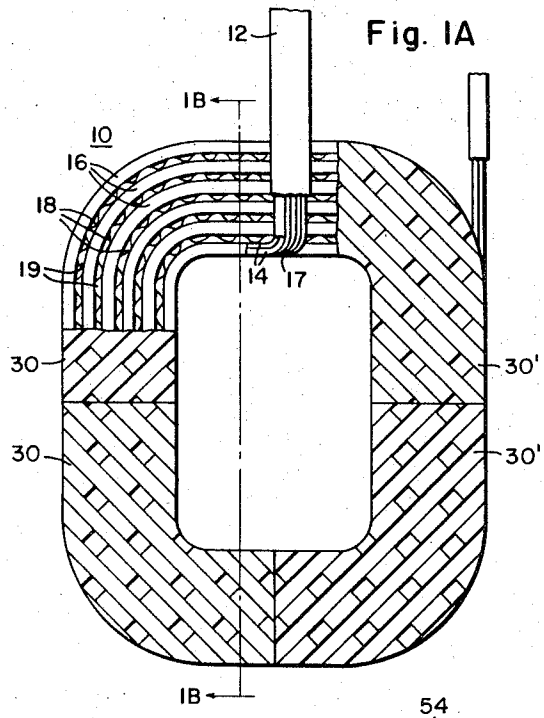
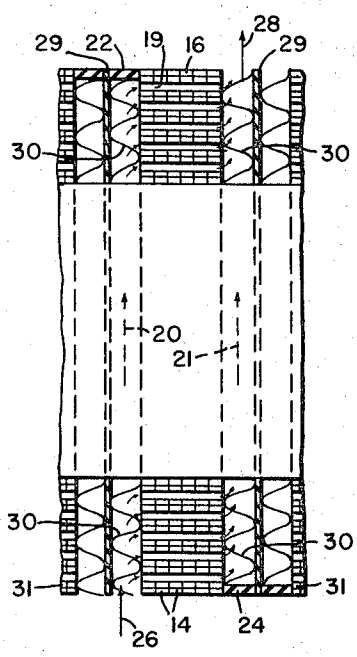


Fig. 1B



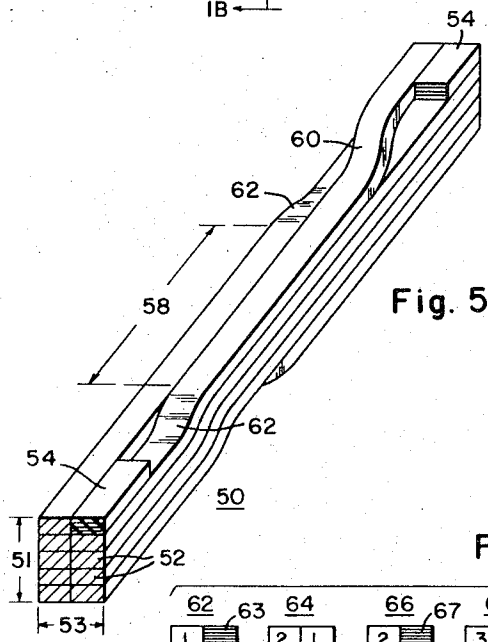


Fig. 5A

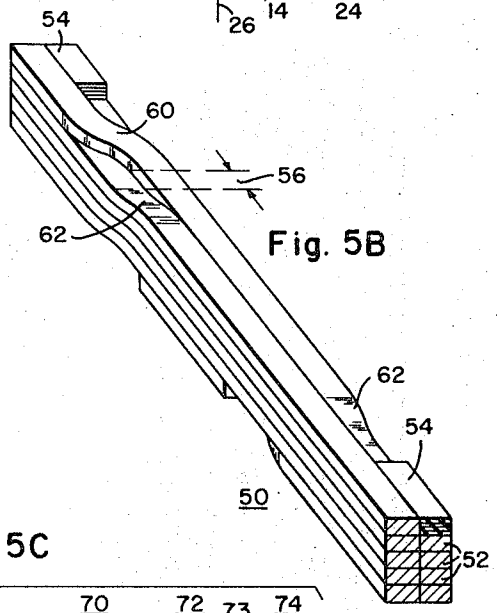
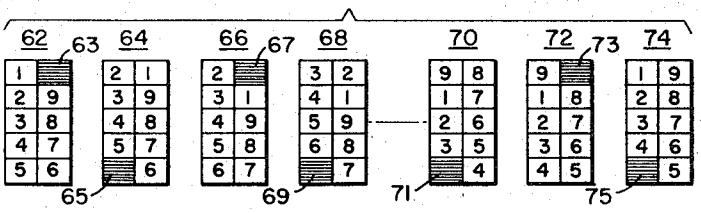


Fig. 5B

Fig. 5C



SPACER FOR PANCAKE COILS

Original Filed May 21, 1962 3 Sheets-Sheet 2

Fig. 2A

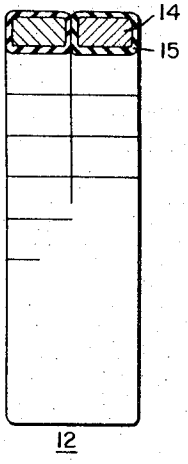


Fig. 2B

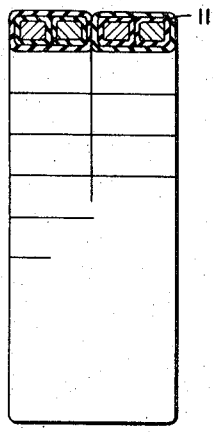
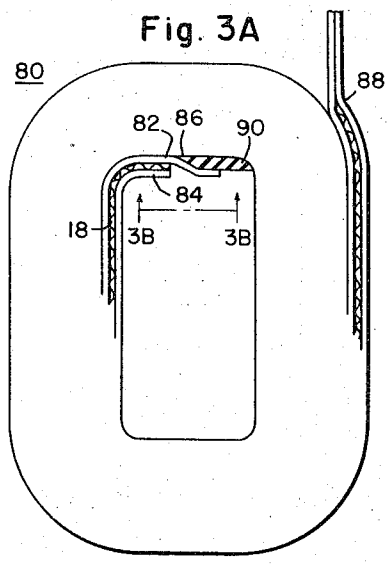


Fig. 3A



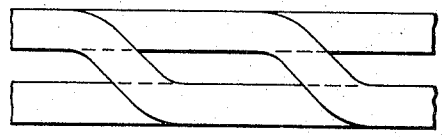


Fig. 3B

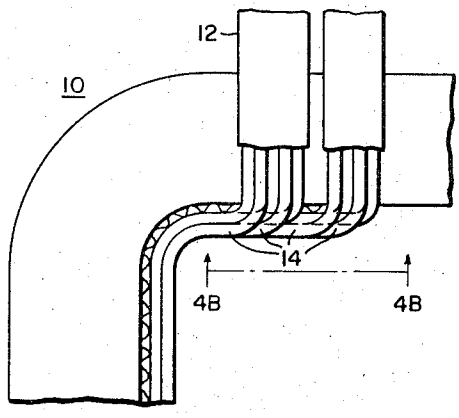
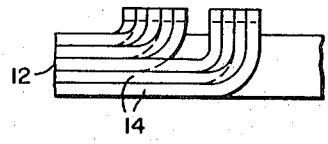


Fig. 4A

Fig. 4B



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Fig. 6A

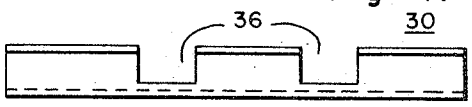


Fig. 6C

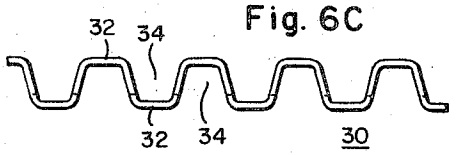


Fig. 6B

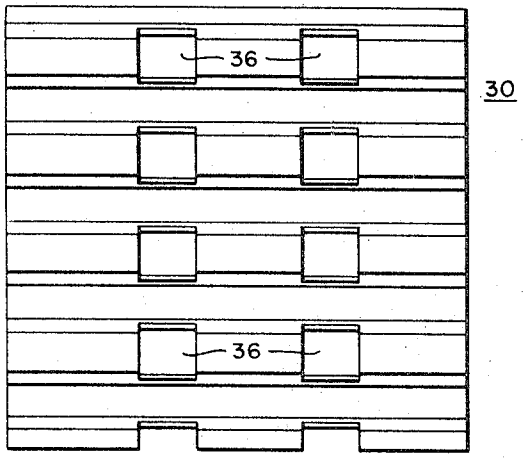


Fig. 7A

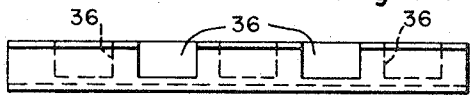
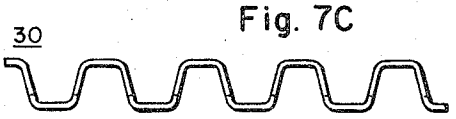


Fig. 7C



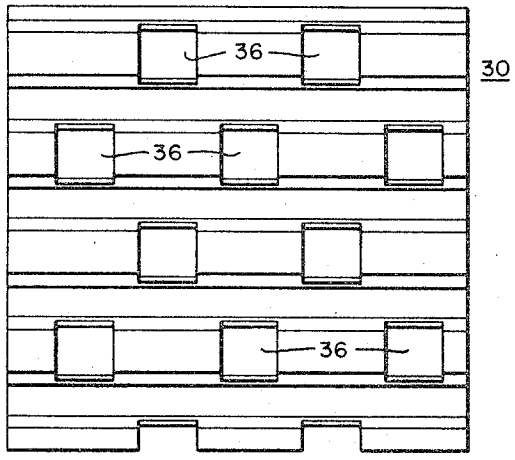


Fig. 7B

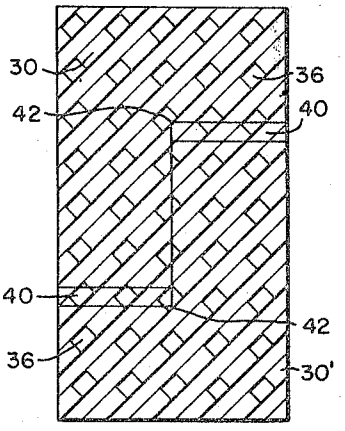


Fig. 8

United States Patent Office 3,368,174 Patented Feb. 6, 1968

3,368,174

SPACER FOR PANCAKE COILS

Heinz G. Fischer, Muncie, Ind., assignor to Westinghouse Electric Corporation, Pittsburgh, Pa., a corporation of Pennsylvania

Original application May 21, 1962, Ser. No. 196,089, now Patent No. 3,252,117, dated May 17, 1966. Divided and this application Oct. 11, 1965, Ser. No. 494,506

3 Claims. (Cl. 336—60)

ABSTRACT OF THE DISCLOSURE

An insulating and spacer member for axially separating pancake type coils in an electrical transformer. The insulating and spacer member is formed of a sheet of electrical insulating material having spaced ridges and furrows, which form first and second wavy opposed surfaces, the extremities of which lie on spaced parallel planes and define the axial dimension of the member. The insulating and spacer member has a plurality of transverse openings therein which extend completely through the member, and which co-operate with the ridges and furrows to direct cooling fluid in the transformer both longitudinally and transversely to said member.

This is a division of application Serial No. 196,089, filed May 21, 1962, now U.S. Patent 3,252,117, issued May 17, 1966.

This invention relates to windings for electrical inductive apparatus, such as transformers, and more particularly to an arrangement of insulation and conductors in the windings of such apparatus.

A method commonly used to construct windings for inductive apparatus is to form a flat disc or pancake type coil from a main conductor comprising a plurality of strands or conducting elements. When the current requirement of the apparatus is high, a sufficient number of these thin pancake coils are connected in a parallel circuit relationship to provide the necessary quantity of conducting material, or the number of strands per conductor has to be increased and the coils are connected in a series circuit relationship. In both cases a multiplicity of brazed joints are necessary to connect the individual coils. The plurality of parallel or series connected coils are separated by thin spacers or washers which give support to the coils and still provide channels or paths which allow a cooling medium to flow in thermal communication with the coils.

When the current requirement of an inductive electrical apparatus is high, it would result in lower manufacturing costs if the winding could be constructed of coils having a larger quantity of conducting material, making it unnecessary to have a multiplicity of brazed joints. However, other problems must be solved if a coil having a large quantity of conducting material is to be as efficient as a plurality of conventional coils connected in a parallel or series circuit relationship.

One such problem is the fact that eddy current losses in a copper conductor of an inductive apparatus, such as a transformer winding, vary with the square of the dimension of the conductor at right angles to the direction of the leakage flux, which in the case of the interleaved type of winding, is approximately at right angles to the axis of the winding or in the plane of the winding coils. To improve efficiency of the electrical inductive apparatus, these eddy current losses are reduced in magnitude by subdividing the required conductor area into a plurality of parallel connected conducting elements or strands, which thereby reduces the dimension of the conductor at right angles with the direction of the leakage flux. The conducting strands or subdivided conductor elements are insulated from each other with paper, enamel, or other

suitable insulation, and the several strands are wrapped or taped together to form a single conductor structure from which a coil is wound. Although the method just described reduces the eddy current losses in the windings of a transformer, there is an offsetting increase in losses due to circulating currents between the parallel connected strands or subdivided conducting elements. Losses due to circulating current in a winding whose coils are formed from parallel connected strands can be reduced by transposing the relative position of the strands with respect to the direction of the leakage flux. This transposing of the strands prevents some strands from being longer than others when they are wound concentrically, and averages out the fact that the self inductance caused by leakage flux is different in the individual strands.

Where the number of strands is small, as in the commonly used pancake type coil, the transposition of the strands can be easily accomplished. However, where high currents must be carried by the winding, several strands must be used and the transposition of the strands presents a greater problem. Cables with a multiplicity of transposed strands which are currently available have many disadvantages in that the conducting structure or cable dimensions increase at the transposition points and the strands spring apart and rub the edges of adjacent strands when the conducting structure or cable is bent with a small radius. It is, therefore, desirable to provide a winding for electrical inductive apparatus having a high current capacity and a plurality of conducting strands. The winding should have a new and improved transposition method to reduce losses due to eddy currents and circulating currents, and at the same time present a high degree of safety from short circuits between adjacent strands in the conducting structure or cable.

Further, since the coil having a large quantity of conducting material is thicker than the conventional pancake coils, cooling the coils becomes a major problem. The method commonly used to insulate adjacent pancake type coils involves cutting diamond or rectangular blocks from a fibrous material and gluing them in a definite predetermined pattern on a thin board formed of a fibrous material. This insulating board or washer insulates and supports adjacent coils and still allows a path for flow of the cooling medium between the coils. This process of constructing the insulating washer, however, is slow and expensive. It is, therefore, desirable to provide a winding for electrical inductive apparatus having a high current capacity and a plurality of conducting strands that has a new and improved cooling method and a new and improved insulating washer to separate the adjacent coils in the winding.

Accordingly, it is an object of the invention to provide a winding for electrical apparatus having an improved insulation arrangement and more efficient path for the flow of the cooling medium.

Briefly, the present invention accomplishes the above cited object by providing a winding for electrical apparatus which is suitable for high currents without brazing a multiplicity of coil sections in parallel or series.

The coil is comprised of a large number of conducting strands per conducting structure and is provided with an improved method for transposing the conducting strands. It is also provided with a new and improved method for cooling the coil turns and a new insulating washer for insulating adjacent coils and provide an improved path for flow of a cooling medium.

Further objects and advantages of the invention will become apparent as the following description proceeds and features of novelty which characterize the invention will be pointed out in particularity in the claims annexed to and forming a part of this specification.

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

FIG. 1A is a plan view of a coil of the type in which this invention may be employed;

FIG. 1B is a cross-sectional view, taken on line 1B—1B of FIG. 1A, showing the relative locations of the conductors and insulating members, and the cooling method employed in this invention;

FIGS. 2A and 2B are cross-sectional views showing construction of main conductors that may be used to form the coil of FIGS. 1A and 1B;

FIG. 3A is a plan view of a coil showing a coil turn formed of a plurality of conductors;

FIG. 3B shows the cross point between two coils;

FIGS. 4A and 4B show how the starting length of a coil is brought out and how the strands are bent to form the starting length;

FIGS. 5A and 5B are right and left-hand isometric views showing the transposition method used in the coil of FIGS. 1A and 1B;

FIG. 5C shows the transposition sequence of the subdivided conductors within the coil of FIG. 1;

FIGS. 6A, 6B and 6C show the side elevation, top plan view and end elevation respectively of an insulating member which is used to insulate adjacent coils;

FIGS. 7A, 7B and 7C show another embodiment of the invention; and,

FIG. 8 shows how the insulating member used to insulate adjacent coils may be cut from one sheet of insulating material.

Referring to FIG. 1A of the drawings, a coil **10** of the type shown may be formed from a main conductor **12** comprising a plurality of parallel connected strands or subdivided elements **14**. FIG. 2A shows a cross section of the main conductor **12** shown in FIG. 1A, illustrating in greater detail the plurality of parallel connected strands **14** and the strand insulating material **15**. If desired, a subdivided strand **11**, as shown in FIG. 2B may be used instead of the single wire strand **14**. The subdivided strand **11** may be used to increase the current capabilities of the coil **10** shown in FIG. 1A without increasing eddy current losses or interfering with the winding procedure. The subdivided strand **11** is handled in the same manner as the single wire strand **14**. The strands **14** are insulated from each other by enamel, paper, or other suitable insulation material **15** and the strands **14** are then taped or wrapped together, usually in two layers, to form a solid conducting structure or main conductor **12**. Referring again to FIG. 1A, the main conductor **12** is then wound into a coil **10**, with each turn **16** of the coil **10** insulated from the adjacent turn **16** by an insulating member **18**. When very large currents are to be carried by the coil **10**, or for other considerations, it may be desirable to connect a plurality of conductors **12** in parallel. FIG. 3A illustrates a coil **80** with two conductors **82** and **84** connected in a parallel circuit arrangement. The conductors **82** and **84** are crossed at the start **86** and finish **88** connections if more than one coil **80** per winding is used. An insulating material, such as pressboard is used to fill the space **90**. FIG. 3B shows the crossing point between two coils viewed from point 3B in FIG. 3A. Connecting a plurality of conductors in parallel also improves the balance in a transformer as it allows a plurality of coils **80** to be connected in a series circuit relation instead of the parallel circuit relation that would be used for coils using a single conductor. An insulating member **18** may be used between the parallel connected conductors **82** and **84**. Referring again to FIG. 1A, the insulating member **18** not only serves to insulate adjacent turns **16**, but it spaces the turns and provides a path for a cooling medium to flow across the coil and in thermal communication with each coil turn transversely. The thin pancake coils in common use provide for coolant to flow longitudinally only. This transverse or cross-flow of cooling medium through the coil makes possible the use of a coil having a multiplicity of conducting elements, because each conducting element in the main conductor is efficiently and adequately cooled.

The insulating member **18** used to insulate adjacent turns must not only have good insulating qualities, but it must also have the strength to support the turns and still provide an adequate path for flow of a cooling medium. A fibrous material, shaped into continuous corrugations, has been found to provide these necessary qualities and is very easy and economical to manufacture. FIG. 1A also shows quarter sections of a new insulation member **30** and **30'** used to support and insulate adjacent coils. This insulating spacer washer **30** and **30'** will be described in detail hereinafter.

Where one, or an odd number of these cross flow type coils are used per winding group, the start conductor is brought out, as illustrated by conductor **12** in FIG. 1A. The standard type coil in use today commonly uses a prepared conductor, consisting of a plurality of insulated and transposed strands, brazed to the coil start **17**. The transpositions are necessary in this prepared conductor because when the prepared conductor crosses the coil **10** adjacent to the turns **16**, the prepared conductor is subjected to a very strong stray field, and because of the relatively short distance between the brazed joint of the prepared conductor to the coil start and the brazed joint to a bushing cable or similar connection.

The design characteristics of the cross flow type coil, however, make the use of a separate prepared conductor and the accompanying brazed joint unnecessary. The cross flow type coil has a very long strand length per coil and the resistance of the strand loop is, therefore, relatively high. This higher resistance makes it practical to use the strands from the conductor that forms the coil to take the place of the prepared conductor, and transposition of the strands is unnecessary during this starting length. FIG. 4A shows in detail how the strands **14** are brought out to form the starting length of the conductor **12** for the coil **10**. The strands **14** are bent so the two layers of strands **14** that form conductor **12**, form one layer of wires while crossing the turns **16** of the coil **10**. FIG. 4B shows the bending of the strands **14** of the conductor **12** to form one layer, viewed from point 4B—4B in FIG. 4A.

FIG. 1B is a cross-section, taken on line 1B—1B of FIG. 1A, with the relative location of adjacent coils **31**, insulating spacer washers **30**, and flat pressboard washers **29** shown to illustrate the cooling medium flow path in detail. The coolant enters the coil at arrow **26** and leaves at arrow **28**. To insure that the coolant traverses the coil through passageways **19** formed by the insulating members **18**, the upper end of longitudinal passage **20** is blocked with a suitable member **22**. The other longitudinal passageway **21** is blocked at the lower end with a member **24**. With this arrangement of passageways, the cooling medium is forced to flow into the coil longitudinally at arrow **26** and along passage **20** formed by insulating spacer washer **30**. Adjacent coils **31** are separated by a flat washer **29** formed of a pressboard or other suitable material. Since passage **20** is blocked by member **22**, the coolant can only flow through the openings **19** between the turns **16** provided by the insulating spacers **18**. When the coolant reaches passage **21**, it cannot flow downward because of blocking member **24**. Therefore, the coolant must flow through insulating spacer washer **30** and from the coil at arrow **28**. It can readily be seen from FIG. 1B that this cross-flow cooling arrangement causes the cooling medium to come into thermal communication with every conducting strand, and, therefore, making possible the use of a large number of conducting strands and hence the design of a very high current coil.

To accomplish this cross-flow cooling design, an insulating spacer or washer **30** and **30'** was developed to insulate and space adjacent coils and at the same time provide

the passageways **20** and **21**, shown in FIG. 1B. It is not only desirable that this insulating washer adequately insulate adjacent coils but it must provide the shortest free copper length, or distance between adjacent supports, to give support to the coil turns under normal and short circuit conditions. However, the obtaining of the shortest possible free copper length should not be accomplished at the expense of covering a large percentage of the coil surface with the insulating washer, as this would unduly hinder the flow of cooling medium.

A method commonly used to form these insulating washers consists of cutting specially shaped blocks from a fibrous material and gluing them to a fiber board in a predetermined pattern. This process is laborious and results in a spacer washer that produces a free copper length of two and three-quarter inches and covers approximately twenty percent of the coil surface.

FIGS. 6A, 6B and 6C show a new spacer washer **30** developed for use in the cross-flow coil. This new spacer washer **30** completely eliminates the cutting and gluing of blocks. The washer consists of a heavy insulating board **30**, corrugated or folded and shaped into parallel ridges and furrows so as to form a wavy surface. Points **32** on the spacer washer **30** contact and support adjacent coils and the cooling medium flows in the channels **34**. To allow the cooling medium to flow transversely to the insulating spacer, as well as longitudinally, and hence allow all the cooling medium to traverse the coil, the washer **30** must have a suitable number of openings **36**, as shown in FIGS. 6A and 6B. The openings **36** in the spacer washer **30** may be milled, punched, sawed or performed in some other suitable manner. If the openings **36** in the spacer **30** are formed by a saw cut, the openings **36** will be in line across the washer **30**, as shown in FIGS. 6A and 6B. If the openings **36** are formed by punching, or by some other suitable method, the openings **36** may be placed in any desirable pattern, as shown in FIGS. 7A, 7B and 7C.

The spacer washer **30** not only provides an insulator between adjacent coils that is inexpensive and easy to manufacture, but it presents greater support to the coil turns with less hindrance to the flow of coolant than the conventional spacer washer. Using the new design spacer washer **30**, the free copper length is reduced as opposed to the conventional washer. Also, the coil surface has less area covered when using the corrugated spacer washer **30** than when using the conventional washer.

FIG. 8 shows an additional advantage of the new corrugated washer **30** as quarter sections **30** and **30'** of the washer **30** may be cut from one large sheet of material **41**. FIG. 8 shows how the cut should be made if a radius **42** is desired on the washer. The strips **40** are the only excess material. FIG. 1A shows the quarter sections **30** and **30'** and how they are placed relative to the coil **10**.

FIG. 1B shows the individual conducting strands **14**, which, as pointed out previously are necessary to reduce eddy current losses. The large number of strands **14** and the efficient cross-flow method of cooling the conducting strands allows the construction of a single high current coil **10**. However, to reduce circulating currents caused by the large number of parallel connected conducting strands **14**, the strands **14** must be transposed, or continuously shifted about the main conductor **12** or cable axis without twisting the strands **14**, and so that each strand **14** successively occupies the same position as is occupied by all the other strands **14**.

One type of transposition, commonly used with a multiplicity of strands, is called the complete transposition. It involves two layers of conductors, with all conductors moving at a common transposition point to the opposite layer and in the mirror image of its original location. In other words, the strand in the upper left corner of one layer of strands would move to the lower right corner of the adjacent layer of strands and the strand in the upper right corner would move to the lower left corner. This process is followed for all the strands. The complete transposition, however, causes a bulging of the main conductor at the transposition point and causes edge-to-edge contact of the strands, making necessary the placement of additional insulation of these points. Also, it is difficult to bend the main conductor in a small radius and impractical to perform the transposition automatically by a bending machine, as the bending angles differ for each strand, depending upon the number of strands used.

Another transposition, commonly called the full transposition, involves two layers of conducting strands, with several transposition points required to complete one full transposition. With this method, each strand moves to the space occupied previously by the adjacent strands. This process is repeated at successive intervals until each strand has occupied the same position as is occupied by all the other strands. Cable presently available using the full transposition has disadvantages in that there is a bulging of the cable at each transposition point and there is an edge-to-edge contact between some of the strands. Edge-to-edge contact of the strands should be avoided if a high degree of safety from short circuits is desirable. When the cable is bent into a coil, the pressure is increased at these edge-to-edge contacts and when the coils are pressed during assembly or stressed due to short circuits while in operation it is highly probably that the protective insulation will eventually become ineffective. This cable is also difficult to bend flat in a small radius because of a tendency of the strands to spring apart and distort the cable.

The transposition method developed for use in the cross-flow coil previously described eliminates the disadvantages of the methods just discussed. FIGS. 5A and 5B show right and left-hand isometric views of a main conductor **50** with the strands transposed according to the principles of the new method. FIG. 5C shows the sequence that may be followed to accomplish the transposition. In particular, a horizontal bend is made changing conducting strand **1** from one layer or row of strands to the other layer or row. Strand **1** is moved into a blank space **63** available in the adjacent layer because an odd number of strands is used to form the main conducting structure. This movement of conductor **1** can be seen in cross-sectional views **62** and **64** of FIG. 5C. Then, the conductive strands **2**, **3**, **4** and **5**, remaining in the layer vacated by strand **1**, are simultaneously bent one conductor space in a vertical direction. Strand **2** takes the place formerly occupied by strand **1**, strand **3** occupies the place previously occupied by strand **2**, strand **4** occupies the place previously occupied by strand **3**, and strand **5** occupies the place previously occupied by strand **4**. This process leaves a blank space **65** as shown in cross-section **64** of FIG. 5C. At the next transition point, the blank space **65** is filled by strand **6**, which is bent horizontally, and the strands **1**, **9**, **8** and **7** remaining in the layer formerly occupied by strand **6** are bent in a vertical direction, leaving a blank space **67** as shown in cross-section **66** of FIG. 5C. This process is repeated until one full transposition has been completed, as shown in cross-section **74**. As many full transpositions of this type may be used per cross-flow coil as may be found desirable.

Although, the above description outlines a transposition where the individual strands move about the main conductor axis in a clockwise direction, as shown in FIG. 5C, it is not meant to be so limited. For instance, the first step in the transposition could be a vertical bend by conductors **9**, **8**, **7** and **6**, as shown in cross-section **62** of FIG. 5C, thus filling the vacancy **63**. The next step would then be a horizontal bend by conductor **5** into the next layer and the space previously occupied by strand **6**. With this method, the strands would rotate counterclockwise about the main conductor axis.

To maintain dimensions **51** and **53** uniform throughout the length of the main conductor or cable **50**, an odd number of conducting strands **52** are used, with the

blank space between transposition points occupied with a filler piece **54** or strip, such as pressboard. Using a filler **54**, the cable **50** can maintain a uniform shape throughout its length, whether or not there is a transposition, and the dimensions of the cable will not change. In summary, an odd number of conductors are used so that the first bend always moves a strand into the vacant space, leaving a vacant space for other conductors, and therefore, allowing all the bends to be made without creating a bulge in the conducting structure.

From FIG. 5C, it can be seen that at each transposition point, only one conducting strand **52** changes from one layer to another, with the other bends being made within one of the layers. As pointed out previously, this conducting strand always moves into a vacant space which is present because of the odd number of conducting strands. Then the remaining conducting strands, in the layer just vacated by the strands moving to the other layer, all simultaneously move one space, thus filling the newly vacated space and creating a space at the other end of the layer. This process is successively repeated until each conducting strand has occupied the space occupied by every other strand, and has made a complete circuit around the axis of the main conductor or cable.

It is very important that all bends **62** performed in the same layer and all bends **60** moving a strand from one layer to the next be made over a very short distance and not gradually. The distance **58**, between the point **62** where all strands are simultaneously bent in one layer, to the point **62** where all strands are simultaneously bent in the other layer, depends upon the number of transpositions required in one coil. However, this distance should not be too small. For example, in one coil design it was found that a minimum distance **58** of three inches was required. The distance between the bend where one strand **52** changes layers or the horizontal bend **60**, and the bend where all conductors in one layer are bent or the vertical bend **62**, is very critical, and should allow enough space for the strand which changes layers to move back and forth. For one coil design this distance was found to be a minimum of three-quarter inch. During distance **56**, all strands **52** have flat surface to flat surface contact and the horizontal transposition or bend **60** can slide back and forth when the main conductor **50** is bent flat, even over a radius as small as 2 inches, without an edge-to-edge contact and resultant insulation scraping.

With this transposition method, all horizontal bends **60** are identical and all vertical bends **62** are identical. Therefore, the angle of the bends is dependent only on the size of the conducting strand **52** and not on the number of conducting strands used. This makes it practical to accomplish the bends in a transposing machine. Also, by accurately bending each strand over a short distance with the same angle, the strands have no tendency to spring out of the main conductor or cable **50** and there is no bulging or change in cable dimension, even when bent flat over a small radius.

It will, therefore, be apparent that there has been disclosed a new and improved winding for electrical apparatus. It is a winding that is capable of carrying high current and yet is efficiently cooled and with low losses due to eddy currents and circulating currents. Also, it is a winding that has an improved insulating arrangement and more efficient path for the flow of cooling medium.

While there have been shown and described what are at present considered to be the preferred embodiments of the invention, modifications thereof will readily occur to those skilled in the art. For example, the coil described in the invention can be used in all windings and machines where a conductor is used which consists of a number of wires that have to be transposed and high degree of safety against wire to wire shorts is desired. Also, since the cross-flow coil is particularly applicable to coils carrying high current, they will generally be used on the low voltage side of inductive apparatus. However, it is not meant to be so limited and the invention is equally applicable to the high voltage side of inductive apparatus. Further, the dimensions given are for illustrative purposes only and are not to limit in any way the subject matter of this invention.

Since numerous changes may be made in the above described apparatus and different embodiments of the invention may be made without departing from the spirit thereof, it is intended that all the matter contained in the foregoing description or shown in the accompanying drawings shall be interpreted as illustrative, and not in a limiting sense.

I claim as my invention:

1. An insulating and spacer member for axially separating, contacting, and mechanically restraining adjacent pancake type coils in an electrical transformer containing a cooling medium, comprising: a substantially flat washer shaped insulating structure having a predetermined outer configuration and a central opening therein; said washer shaped insulating structure being formed of at least one sheet of electrical insulating material, said at least one sheet of electrical insulating mtaerial having a plurality of spaced ridges and furrows which form first and second wavy opposed surfaces, the extremities of which lie on first and second spaced parallel planes and define the effective axial dimension of the insulating structure; said sheet member having a plurality of transverse openings therein which extend completely through said sheet member, and which are defined, at least in part, by certain of the extremities of its wavy surfaces; said ridges and furrows and said plurality of transverse openings in said sheet member cooperating to direct a cooling fluid both longitudinally and transversely to said sheet member, when it is disposed between axially adjacent coils of the electrical transformer.

2. The insulating and spacer member of claim **1** wherein said substantially flat washer shaped insulating structure includes a plurality of said sheet members disposed in substantially the same plane and arranged in contacting relation, to each define a portion of the predetermined outer configuration, and a portion of the central opening of said washer shaped insulating structure.

3. The insulating and spacer member of claim **2** wherein the relative direction of the ridges and furrows is different in at least certain of said plurality of sheet members.

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