United States Patent

Foster

[15] **3,668,587**

[45] **June 6, 1972**

[54] MULTI-LAYER POLYPHASE WINDING MEMBER AND TRANSFORMER

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[21] Appl. No.: **36,913**

[52] **U.S. Cl.** **336/123,** 336/129

[51] **Int. Cl.** **H01f 21/04**

[58] **Field of Search** 336/115, 119, 120, 122, 123, 336/129

[56] **References Cited**

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3,441,888	4/1969	Farrand	336/123
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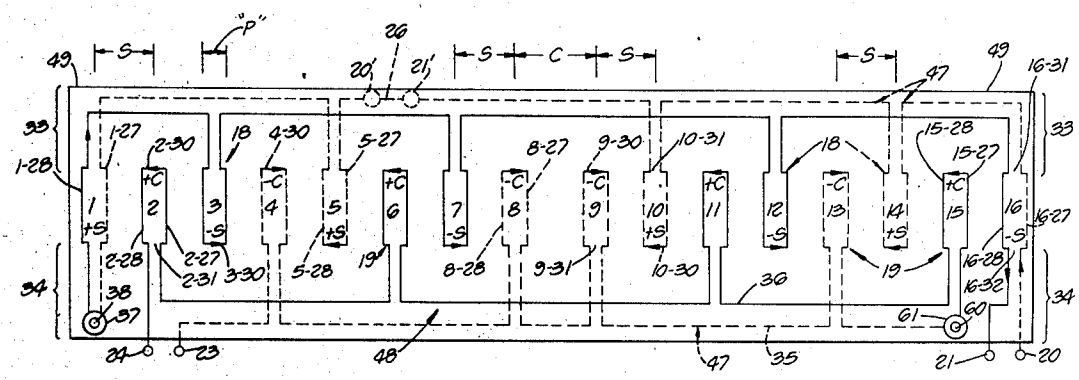
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[57] **ABSTRACT**

Disclosed is a polyphase member for a position measuring transformer formed by multiple layers of printed circuit active and inactive conductors. The inactive conductors connect the active conductors to form winding sections and the winding sections are interconnected by printed circuit inactive conductors to form polyphase windings. Each layer includes groups of conductors including a predetermined number, usually an equal number, of active conductors of first and of second cofunction, e.g., sine or cosine, types. The winding sections are positioned with a specific phase relationship, such as quadrature, to a reference winding. The active conductors on each layer of the polyphase member are positioned such that a blank area called an active conductor void or gap, occurs where normally in a periodic configuration an active conductor would be positioned. Still further, the layers are complementary in that they are combined into a multi-layer member so that the active conductors on one layer are superposed the active conductor voids or gaps on another layer whereby the multi-layers as a whole present to the reference winding uniformly spaced active conductors.

19 Claims, 12 Drawing Figures



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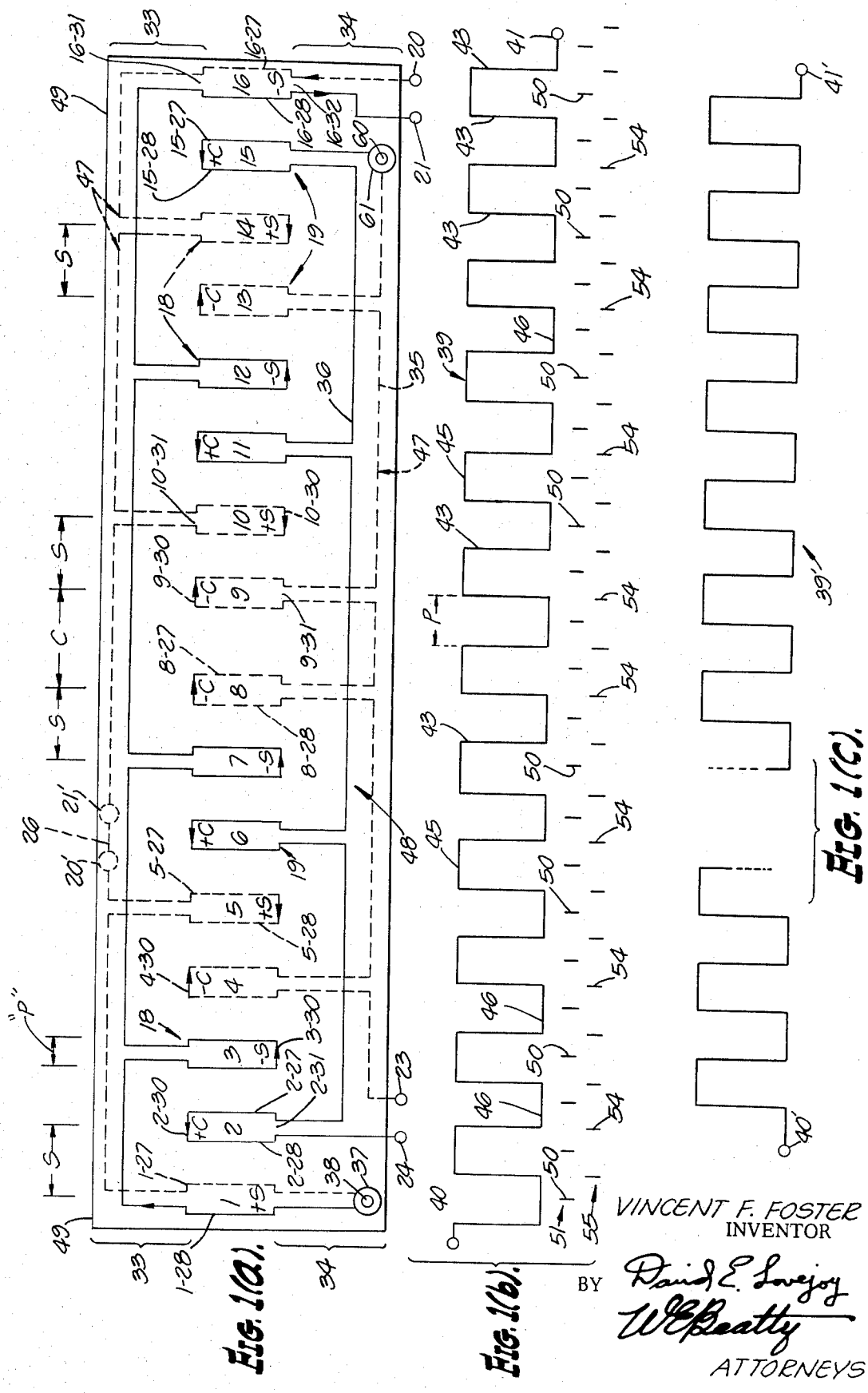


FIG. 1(A).

FIG. 1(B).

FIG. 1(C).

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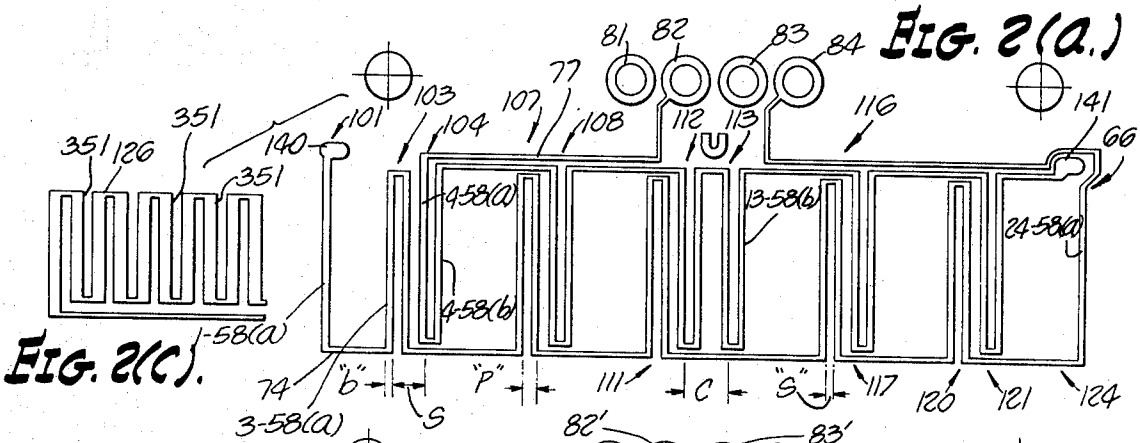


FIG. 2(a.)

FIG. 2(c).

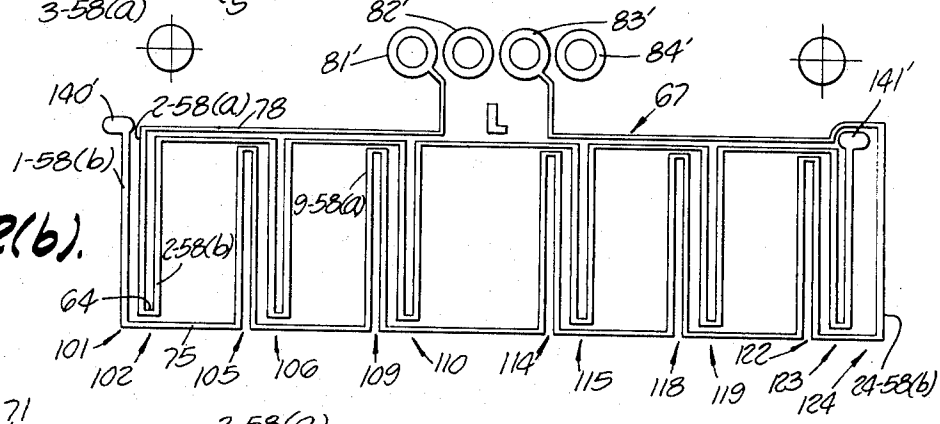


FIG. 2(b).

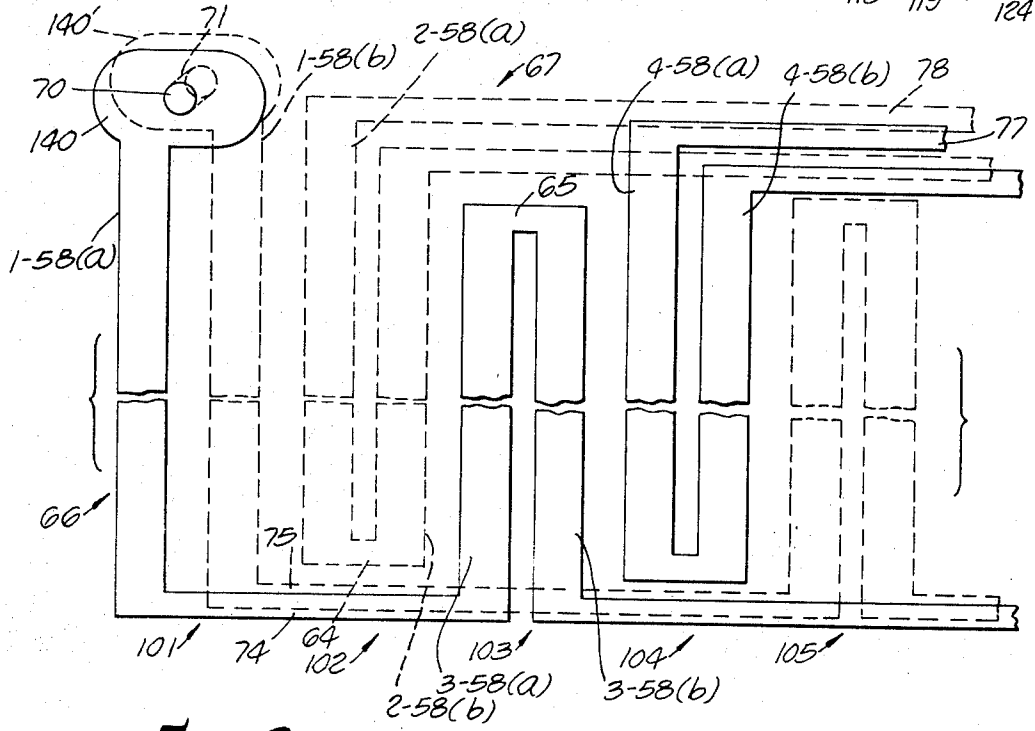


FIG. 3.

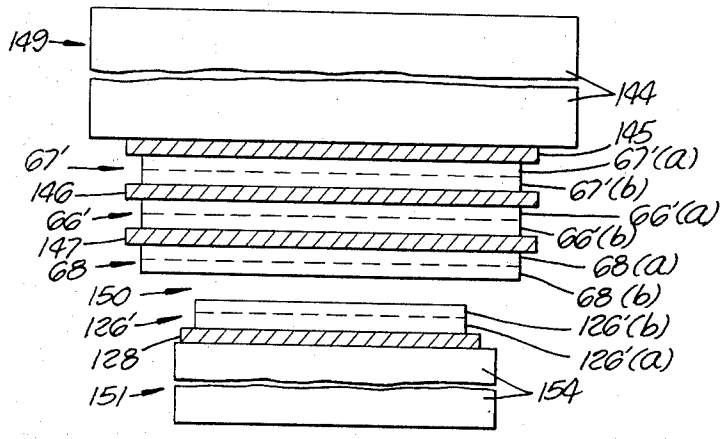

149
144
145
67'
67'(a)
146
67'(b)
66'
66'(a)
147
66'(b)
68
68(a)
150
68(b)
126'
126'(b)
128
126'(a)
151
154

FIG. 4.

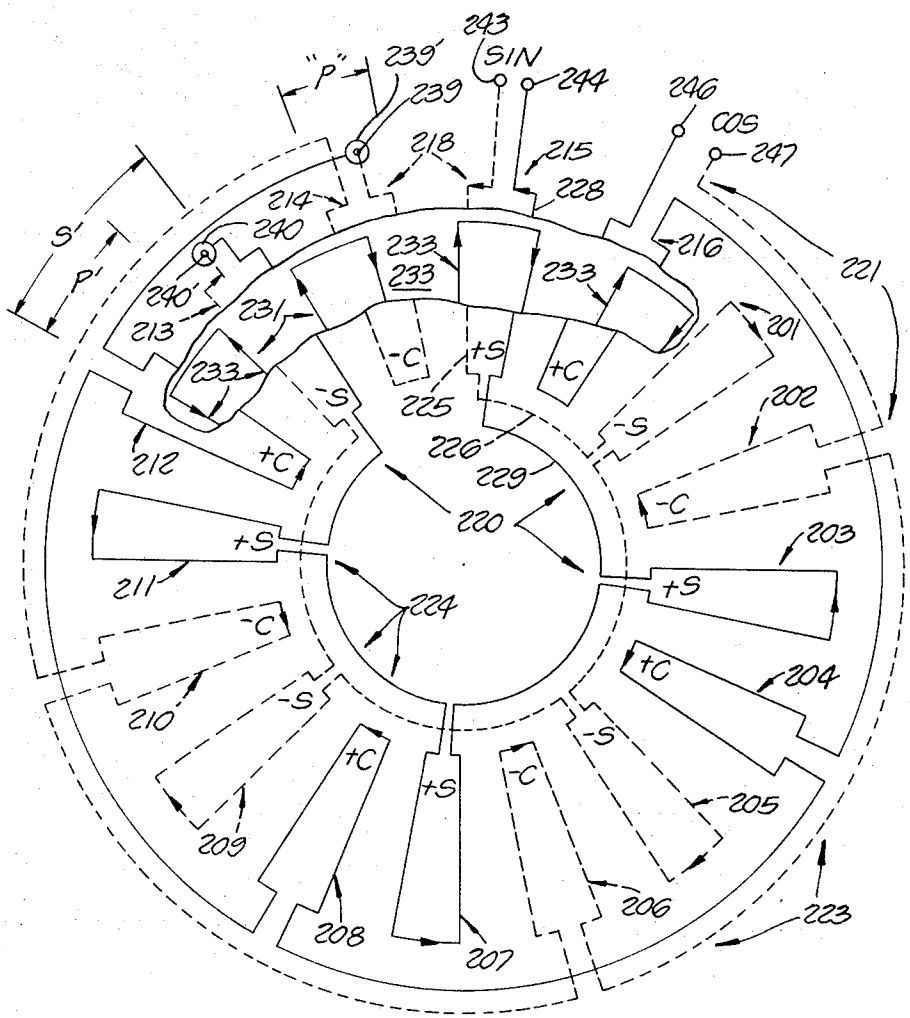

243
SIN
"P"
239'
239
244
246
COS
247
218
215
214
228
216
221
240
240'
213
231
233
201
202
-C
+S
+C
-S
225
226
229
212
220
203
211
224
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210
205
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206
208
207
223

FIG. 5.

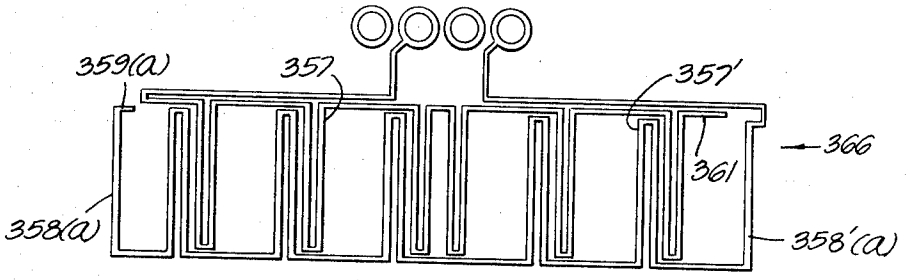


FIG. 6(a).

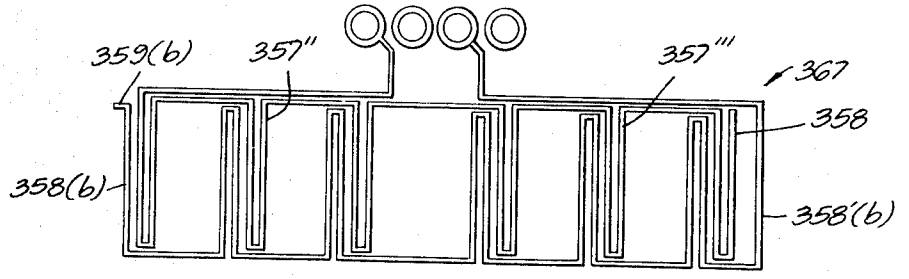


FIG. 6(b).

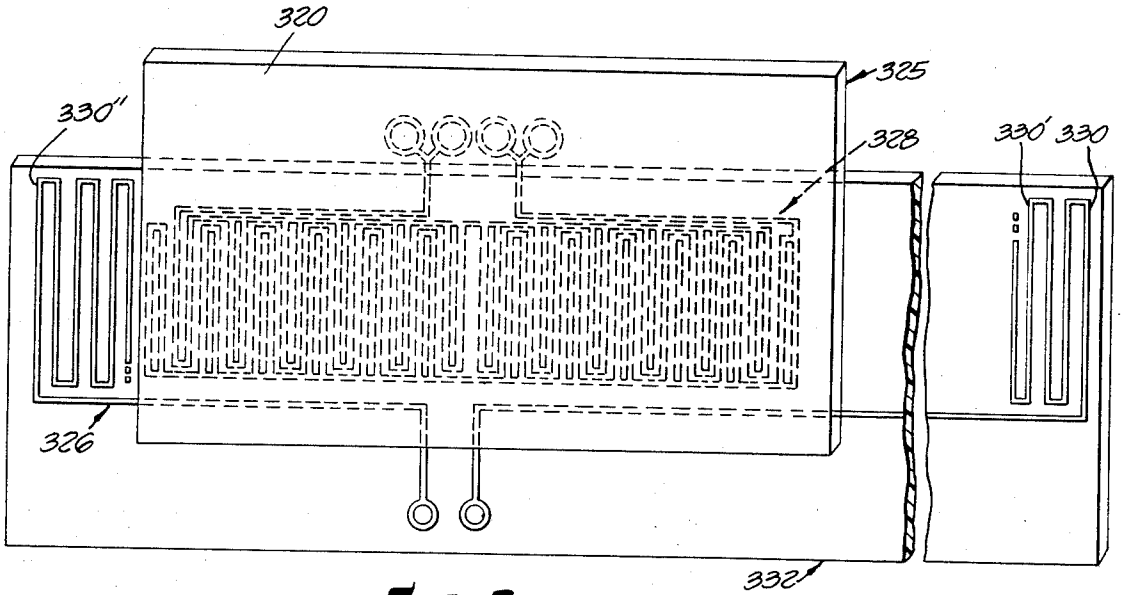


FIG. 7.

MULTI-LAYER POLYPHASE WINDING MEMBER AND TRANSFORMER

BACKGROUND OF THE INVENTION

This invention relates to position measuring transformers of the type in which two relatively movable members are provided, one having at least two planar windings (called polyphase windings) which are phase shifted in space relative to each other and inductively coupled to another planar winding carrier by the other member.

When one winding on one member is energized with an alternating primary voltage, the current in that winding induces a secondary voltage in any winding on another member which happens to be in close proximity thereto.

In practice, position measuring transformers have employed on one member a single winding formed from uniformly spaced, series-connected active conductors. That member is usually a single-phase member which conventionally defines a reference pitch, that is, defines a periodic spacing of the active conductors. In practice, for linear devices the single-phase member is called the "scale" and for rotary devices it is called the "rotor."

The other relatively movable member of position measuring transformers generally includes two windings, each phase-shifted in space with respect to the other thereby presenting two different phases to the single-phase member, and hence that other member is called the polyphase member. Conventionally, the polyphase member is called the "slider" in the case of linear devices and the "stator" in the case of rotary devices. While the polyphase member (slider or stator) has windings which are phase-shifted in space with respect to each other, those windings have a specific phase relationship to the single winding on the single-phase member (scale or rotor).

The phase-shift between the windings, called polyphase windings, on the polyphase member is generally one quarter of the cycle of the winding on the single-phase member. Accordingly, the phase shift between the polyphase windings is a quadrature phase shift and hence is a phase shift analogous to the quadrature phase shift between sine and cosine trigonometric functions. When the polyphase windings are shifted a quarter cycle, they are, therefore, conventionally identified as the sine and cosine windings. While sine and cosine windings are conventional, other phase shifts, of course, may be implemented. For example, 120° shifts between each of three windings may be employed to form a three-phase system. Broadly, the term "polyphase" describes all such phase-shifted windings. Additionally, the term "cofuction" is also generically used to describe the polyphase windings of position measuring transformers since "sine" and "cosine," for example, are trigonometric cofunctions of the same angle.

Position measuring transformers of the above type have been known and used for many years. For example, the U.S. Pat. No. 2,799,835 to R. W. Tripp et al., discloses a transformer of the above type employing planar windings. Although the improvements disclosed in the Tripp et al., patent resulted in a more accurate transformer, some embodiments of the latter are difficult to manufacture, particularly because the intricate wiring patterns of polyphase windings have required large numbers of soldered or welded wire connections. For example, in order to properly connect the various active conductors comprising the windings, i.e., those conductors extending transversely of the direction of relative movement of the members, a hole must be drilled in the supporting member of glass or the like adjacent each conductor group and connector wires passed through the holes and soldered or welded to the conductors. In a typical case, wherein the polyphase winding support member comprises 24 conductor groups, 24 holes, 48 wires and 48 soldered or welded wire connections would be required.

Improvements to the polyphase member of position measuring transformers are disclosed in U.S. Pat. Nos. 2,915,722 and 2,924,798 to Vincent F. Foster. Briefly, the U.S. Pat. No. 2,915,722 patent teaches reducing unwanted components of induced voltage by providing first and second polyphase windings on the slider which are physically located symmetrically with respect to a common center line. The U.S. Pat. No. 2,924,798 adds the additional improvement of interwiring first and second cofunction winding sections in a set sequence thereby reducing unwanted induced voltages in the secondary.

While the improvements in sliders represented by the U.S. Pat. Nos. 2,915,722 and 2,924,798 have resulted in significantly better operation of the position measuring transformers of which they form a part, these improvements have not eliminated the complex nature of sliders or other polyphase members and particularly have not eliminated intricate wiring patterns which exhibit large numbers of wire crossings and soldered connections.

Later developments, such as those disclosed and claimed in the U.S. Pat. No. 3,441,888 to C. L. Farrand, have attempted to further improve and simplify the construction of such measuring transformers. The latter patent discloses multiple layer planar windings wherein sine and cosine conductor groups are staggered with respect to sine and cosine conductor groups on another layer. Although an increase in accuracy and other benefits are attained by this arrangement, the assembly of the various conductor groups still necessitates a considerable number of wired connections between different conductor groups in the different layers. The nature of such connections, because of their cross wire relationship, still necessitates a considerable number of soldered or welded connections which, in many cases, must be done by hand. This considerable number may reduce the reliability of the transformer.

SUMMARY OF THE INVENTION

The present invention is a polyphase winding member and winding arrangement for a position measuring transformer which requires far fewer soldered or welded wire connections than is required by prior art transformers of this type. Specifically, in one embodiment only two such connections, other than the necessary terminals, are required regardless of the number of groups of active conductors employed. Thus, the resulting transformer requires less labor to manufacture and effects a significant increase in reliability.

The polyphase member of the present invention includes multiple layers of active conductors. Groups of the active conductors are connected by inactive conductors to form winding sections and the winding sections are interconnected to form polyphase windings. Each layer includes a predetermined number, usually an equal number, of active conductors of first and of second cofunction types. The winding sections are positioned with a specific phase relationship to a reference winding. That reference winding is typically a single-phase winding on a stationary member of a position measuring transformer. Further, the active conductors on each layer of the polyphase member are positioned such that there occurs a void, that is, a space or gap characterized by the absence of one or more active conductors where normally in a periodic configuration complementary active conductor or conductors would be located. Still further, the layers are combined into a multilayer member so that the active conductors on one layer are positioned opposite active conductor voids on another layer. The multi-layer member thus formed typically includes a plurality of interdigitated cofunction winding sections.

The groups of active conductors forming winding sections in different layers have groupings and spacial relations such that they are connected by inactive conductors lying in the same layers but generally having no magnetic inductive relation thereto so that the active conductors and their connecting inactive conductors are all formed mainly by printed circuit techniques.

Also, according to the present invention, one layer contains a pattern of interspaced groups of active conductors of one significance, e.g., sine, and groups of active conductors of another significance, e.g., cosine, while another layer contains

a complementary and overlying pattern of such groups to form an array of interspaced groups of the two significances, with as few as a pair of circuit connections extending between the layers to connect the groups of similar significance.

Further, the particular arrangement of the groups of active conductors and their connecting inactive conductors enables such groups to be symmetrically arranged about a center line to reduce unwanted components of induced voltages while maintaining the inactive conductors generally out of magnetic inductive relation to such groups.

A further feature of the invention is the arrangement wherein the inactive conductors connecting active conductors in one layer are located in inductive coupling relation to the inactive conductors connecting active conductors in another layer such as to reduce or cancel the undesired one-turn loop coupling which would otherwise occur.

A still further feature of the invention is the arrangement of an array of winding sections formed by groups of active conductors certain of which are connected by inactive conductors in the same layer leading to one margin or marginal area of the array and others of which are connected by inactive conductors in the same layer leading to the opposite margin or marginal area of the array. By providing two layers of such winding sections, four such margins are provided for locating the connecting inactive conductors to eliminate wire cross-over points.

A still further feature of the invention which enables attainment of the above results is that groups of active conductors have one active conductor located in one layer and another active conductor located in another layer.

The foregoing and other objects, features, and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1(*a*) is an enlarged plan view of a slider wherein the sine and cosine windings are arranged in two layers, each layer consisting of a printed circuit which includes both active conductors, which are generally the transverse conductor portions, and inactive conductors, which are generally the longitudinal conductor portions, the active conductors and inactive conductors in full lines consisting of a printed circuit in one layer, the active conductors and inactive conductors appearing in broken lines appearing in another layer.

FIG. 1(*b*) depicts a schematic plan view of a single-phase reference winding, having active conductors defining a reference pitch, which reference winding is relatively movable with respect to the polyphase member of FIG. 1(*a*) to which it is inductively coupled.

FIG. 1(*c*) depicts a schematic plan view of the winding like that of FIG. 1(*b*) but shifted in space one-quarter cycle with respect to the FIG. 1(*b*) position.

FIG. 2(*a*) depicts an enlarged plan view of an upper layer, having 24 active conductors, of a polyphase member comprised of 48 active conductors.

FIG. 2(*b*) depicts an enlarged plan view of the lower layer, having 24 active conductors, of a polyphase member having an upper layer like that depicted in FIG. 2(*a*).

FIG. 2(*c*) depicts a portion of a reference winding positioned to show its relative size with respect to the FIG. 2(*a*) sections.

FIG. 3 depicts a front view of a portion of the FIG. 2(*a*) and FIG. 2(*b*) layers superposed but drawn slightly offset to show their overlay position and with the bottom layer shown dotted.

FIG. 4 depicts a cross-Sectional end view of a position measuring transformer having a polyphase member positioned, with a gap, over a single-phase member.

FIG. 5 depicts a rotary embodiment, patterned after FIG. 1(*a*), of a polyphase member of the present invention.

FIG. 6(*a*) and FIG. 6(*b*) depict alternate embodiments of upper and lower layers, respectively, similar to the layers of FIG. 2(*a*) and FIG. 2(*b*).

FIG. 7 depicts the layers of FIG. 6(*a*) and FIG. 6(*b*) overlaid on a base to form a polyphase winding member and depicts that polyphase winding member above a single-phase winding member where the latter has active conductors longer than the active conductors of the former.

DETAILED DESCRIPTION

FIG. 1(*a*) depicts a polyphase member having polyphase (also called cofunction) windings in the form of a sine winding **18** and a cosine winding **19**. The sine winding **18** is connected between terminals **20** and **21** and the cosine winding **19** is connected between terminals **23** and **24**. Both the sine and cosine windings **18** and **19** are comprised of a plurality of winding sections, numbered left to right from **1** to **16**. Some of the winding sections are on one layer **47** and some are on another layer **48** and some are on both. Since FIG. 1(*a*) is a top view and in schematic form, the layers **47** and **48** are not observable as such therein but are shown and described in connection with FIGS. **2**, **3** and **4** hereinafter. The layers **47** and **48** are separated by an insulator layer **49**.

In FIG. 1(*a*), the sine winding **18** is comprised of winding sections **1**, **3**, **5**, **7**, **10**, **12**, **14** and **16** and the cosine winding **19** is comprised of winding sections **2**, **4**, **6**, **8**, **9**, **11**, **13** and **15**. Winding sections **4**, **5**, **8**, **9**, **10**, **13** and **14** are in one layer and winding sections **2**, **3**, **6**, **7**, **11** and **12** are in the other. Winding sections **1** and **16** are formed by active conductors from each layer. The winding sections, or more simply sections, and other conductors, such as inactive conductor **36** between sections **11** and **15**, which appear on layer **48** are represented by solid lines. In order to distinguish layers, the sections and other conductors, such as inactive conductor **35** between sections **9** and **13**, appearing on the layer **47** are shown as broken lines.

Each winding section for the polyphase member of FIG. 1(*a*) includes two active conductors **−27** and **−28**. Each of the active conductors **−27** and **−28** is given a prefix corresponding to the appropriate winding section. For example, the active conductors for section **2** are designated as **2–27** and **2–28**. Each of the active conductors **−27** and **−28** for the 16 sections of FIG. 1(*a*) terminates with an end in one direction forming a first upper margin on insulator **49** and terminates with an end in an opposite second direction forming a second lower margin on insulator **49**. Each of the conductors **−27** and **−28** is connected on its ends by an inactive conductor **−30** where again the particular inactive conductor is prefixed with the appropriate corresponding section number. For example, section **2** has active conductor **2–28** connected along the upper margin **33** to active conductor **2–27** by the inactive conductor **2–30**. Most of the sections of FIG. 1(*a*) have section openings **−31** along one margin opposite inactive conductors **−30** along the opposite margin where the prefix notation is again employed. For example, section **2** has a section opening **2–31** along the bottom margin **34** opposite the inactive conductor **2–30**.

In FIG. 1(*a*) winding section **16** does not include an inactive conductor **−30** and the active conductors **16–27** and **16–28** are on different layers. With the active conductors on different layers and no inactive conductor, terminals **20** and **21** are readily located along margin **34** rather than along margin **33** so that winding section **16** provides for an across-the-winding placement of those terminals. If opening **16–32** were replaced by an inactive conductor **16–30** (not shown) connecting the inactive conductors **16–27** and **16–28**, then terminals **20** and **21** would be typically positioned along margin **33** shown, for example, as alternate terminals **20′** and **21′**. When an inactive conductor **16–30** is provided in place of terminals **20** and **21**, the inactive conductor portion **26** between terminals **20′** and **21′** is, of course, removed.

While winding section **16** provides for across-the-winding placement of terminals **20** and **21**, winding section **1**, with opening **1–32**, analogously provides for across-the-winding placement of interconnecting tabs **37** and **38**. The across-the-winding placements achieved with sections **1** and **16** allows all

of the terminals (**20, 21, 23, 24**) and interconnection tabs (**37, 38, 60, 61**) to be located along margin **34** with none along margin **33**. This single margin location is useful in preventing those tabs and terminals from coupling to the terminals of the single-phase winding placed on the opposite margin as shown in FIG. **7**.

The active conductors **–27** and **–28**, such as **2–27** and **2–28**, of FIG. **1**(*a*) are included in winding sections which appear, also referring to FIG. **1**(*b*), at selected intervals **50** of a first plurality of periodic intervals **51** and at selected intervals **54** of a second plurality of periodic intervals **55**. The periodic spacing of the winding sections **1** through **16** of FIG. **1**(*a*) can best be explained with respect to a reference. The reference is typically a single-phase winding of a position measuring transformer like that schematically shown in FIG. **1**(*b*).

FIG. **1**(*b*) depicts a continuous winding **39** which is connected between terminals **40** and **41**. Continuous winding **39** is comprised of a plurality of periodic, parallel, series-connected active conductors **43**. The active conductors **43** are connected at their terminations along the top by inactive conductors **45** and at their termination along the bottom by conductors **46**. Active conductors **43** are spaced periodically at a distance P and therefore are said to have a pitch of P. The continuous winding **39** is cyclic over each distance of 2P, that is, P is a half cycle of the reference.

The spacing of the winding sections of FIG. **1**(*a*), relative to the continuous winding **39** as a reference, is such that winding sections **1, 3, 5, 7, 10, 12, 14** and **16**, which form the sine winding **18**, are centered at selected intervals **50** associated with the first plurality of periodic intervals **51**. The first plurality of periodic intervals **51** appear every half cycle, P, of continuous winding **39**, as shown for example with reference to FIG. **1**(*b*), at the midpoints of each of the inactive conductors **45** and **46**.

The winding sections **2, 4, 6, 8, 9, 11, 13**, and **15** forming the cosine winding **19** in FIG. **1**(*a*), appear at selected intervals **54** of the second plurality of periodic intervals **55**. The second plurality of periodic intervals **55** is phase-shifted from the first plurality of periodic intervals **51** one-quarter of a cycle, (2P)/4, of continuous winding **39**.

In order to obtain the desired quadrature relationship between sine winding **18** and cosine winding **19**, the individual winding sections **1** through **16** are spaced at periodic intervals which have a quadrature relationship, namely, spaced at the first plurality of periodic intervals **51** or at the quarter-cycle-shifted second plurality of periodic intervals **55**. While the winding sections for sine winding **18** may be placed at any of the periodic intervals **51** and the winding sections for cosine winding **19** may be placed at any of the periodic intervals **55**, the spacing at the selected intervals **50** and **54**, respectively, of FIG. **1** is typical.

The section spacing, C, between the central two sections, sections **8** and **9**, is typically selected equal to "*n*"P in accordance with the above-referenced Foster U.S. Pat. No. 2,915,722 where "*n*" equals the even number of active conductors per section and P is the reference half-cycle. Selecting C in that manner insures that the sine and cosine windings **18** and **19** of FIG. **1**(*a*) will each have their equal number of winding sections symmetrically located with respect to a center line running between sections **8** and **9**.

FIG. **2**(*a*) depicts the upper of two layers of a multi-layer, polyphase member in accordance with the present invention. FIGS. **2**(*a*) and **2**(*b*) are drawn to a scale of approximately 1 ½ times actual size for a slider in accordance with one preferred embodiment of the present invention. FIG. **2**(*b*) depicts the lower layer used in cooperation with the upper layer of FIG. **2**(*a*). The layers of FIGS. **2**(*a*) and **2**(*b*) are designed with center spacing C of the order of 0.2000 inches, the spacing "*p*" between active conductors of the order of 0.0333 inches, and the section spacing, "S," of the order of 0.15 inches. Additionally, the width "*b*," of a typical active conductor **3–58**(*a* is approximately one-third "*p*" or 0.011 inches. Accordingly, the gap, "*s*," between active conductors equals "*p*" minus "*b*" or alternatively, "*b*" equals 2" *s*."

The upper layer **66** depicted in FIG. **2**(*a*) consists of 24 active conductors, like typical active conductor **3–58**(*a*), which individually form at least portions of the winding sections **101, 103, 104, 107, 108, 111, 112, 113, 116, 117, 120, 121** and **124**. The active conductors are identified by the prefix notation like that previously employed. Interspersed between the winding sections are a plurality of winding section voids, that is gaps or blank spaces where, in a periodic configuration, a winding section would normally occur. Particularly, winding section voids occur between winding sections **101** and **103, 104** and **107, 108** and **111, 113** and **116, 117** and **120**, and **121** and **124**.

In a similar manner, the lower layer **67** of FIG. **2**(*b*) includes at least portions of winding sections **101, 102, 105, 106, 109, 110, 114, 115, 118, 119, 122, 123** and **124**. In FIG. **2**(*b*), winding section voids are interspersed between winding sections **102** and **105, 106** and **109, 110** and **114, 115** and **118, 119** and **122**.

The winding sections **101** and **124** are formed by active conductors **1–58**(*a*), **1–58**(*b*), **24–58**(*a*) and **24–58**(*b*) from each of the FIG. **2**(*a*) and FIG. **2**(*b*) layers. The active conductors on each layer for winding sections **101** and **124** overlay active conductor voids on the other layer. More particularly, winding section **101** is formed by an active conductor **1–58**(*a*) in upper layer **66** together with the active conductor **1–58**(*b*) from the lower layer **67**. Similarly, active conductor **24–58**(*a*) is in upper layer **66** and active conductor **24–58**(*b*) is in lower layer **67** and together they form winding section **124**.

In order to provide for a through-layer connection, active conductor **1–58**(*a*) terminates in a tab **140** and active conductor **1–58**(*b*) terminates in a tab **140'**. A second through-layer connection is provided for between winding section **121** and winding section **123** by tabs **141** and **141'**.

When the layers of FIGS. **2**(*a*) and **2**(*b*) are superposed (as partially shown in FIG. **3**), the tabs **140** and **141** are connected to the tabs **140'** and **141'**, respectively, in any conventional manner so as to make a through-layer connection. For example, a hole **70** is drilled through the upper layer tab **140** allowing a soldered connection **71** to be made through to the lower layer tab **140'**.

FIG. **3** depicts a portion of the upper layer **66** of FIG. **2**(*a*) superposed over a portion of the lower layer **67** of FIG. **2**(*b*), with the layers drawn slightly shifted from their actual position so that the lower layer may be seen in the drawings. Although not shown exactly superposed, the inactive conductor **74** on layer **66**, connecting winding section **101** to winding section **103**, is intended to be identically superposed over inactive conductor **75** connecting winding section **101** to winding section **105**. In a similar manner, inactive conductor **77** from winding section **104** is intended to be identically superposed over a portion of inactive conductor **78** from winding section **102**. The purpose of superposing the inactive conductors from layer to layer is to reduce the unwanted coupling which might otherwise be generated by inactive conductors. Besides superposing, the inactive conductors generally must be connected such that they carry current in opposite directions. For example, the magnetic field generated by a current through inactive conductor **74** is effectively cancelled by the equal but opposite current through inactive conductor **75**. It is evident that current is equal and opposite because active conductors **1–58**(*a*) and **1–58**(*b*) are series-connected by a through-layer connection **71** between tabs **140** and **140'**. Inspection of FIGS. **2**(*a*) and **2**(*b*) in conjunction with the partial view in FIG. **3** reveals a similar equal but opposite current relationship between most of the superposed inactive conductors of the upper layer **66** and the lower layer **67**. As a further example, the equal but opposite current relationship exists between the superposed inactive conductors **77** and **78**.

It is also apparent from FIG. **3**, in accordance with the present invention, that the winding sections on one of the two layers of FIG. **3** are positioned in the winding section voids of the other layer in FIG. **3**. For example, winding sections **103** and **104** on the upper layer **66** are positioned in the winding section voids appearing between the winding sections **102** and

105 on the lower layer 67. Similarly, the winding section 102 and the active conductor 1–58(*b*) appearing on the lower layer 67 are positioned in the winding section voids between winding section 103 and active conductor 1–58(*a*) on the upper layer 66. The term "superposed with" has a meaning which is generic to and covers the terms "positioned in" as used in this paragraph and the terms "opposite," "superposed over" and "superposed" as used in other parts of the specification without regard to whether an upper layer or a lower layer is intended.

When the upper layer 66 and the lower layer 67 are superposed as shown in FIG. 3 and the tabs 140 and 140' (and also tabs 141 and 141' not shown in FIG. 3) are connected with a through-layer connection 71 as indicated, continuous sine and cosine windings are formed. The sine winding terminates in tab 84 on the upper layer 66 and tab 83' on lower layer 67. The continuous cosine winding similarly terminates in tab 82 on upper layer 66 and tab 81' on lower layer 67. In a manner analogous to the interconnection of tabs 140 and 140', the tabs 81, 82, 83 and 84 may be interconnected with the tabs 81', 82', 83', and 84', respectively, in order to provide for external connections to the windings at outside points.

With the through-layer connection of tabs as indicated above, the sine winding is comprised of sections 101, 103, 105, 107, 109, 111, 114, 116, 118, 120, 122 and 124. Similarly, the cosine winding is comprised of winding sections 102, 104, 106, 108, 110, 112, 113, 115, 117, 119, 121 and 123. It is apparent that a composite winding including an upper layer 66 and a lower layer 67 includes interdigitated sine and cosine sections in which there are an equal number of active conductors on each layer and further in which on each layer there is the same number of active conductors associated with sine winding sections as with cosine winding sections.

In accordance with the present invention, the superposed printed layers in FIG. 3 have complementary arrays of active conductors which when viewed as a composite provide uniformly spaced active conductors of sine and cosine significance. Furthermore, the interdigitation of the sine and cosine winding sections is reversed at winding sections 112 and 113 thereby incorporating the teaching of the above-identified U.S. Pat. No. 2,915,722 patent.

Because of the symmetry provided by having an equal number of active conductors per layer, by having the same number of active conductors in sections associated with the sine winding as with the cosine winding on each layer, and by having interdigitated winding sections, the exactness with which the layers must be superposed during the manufacturing process is reduced. Shifts of one layer with respect to the other layer are tolerable because the unwanted induced voltages caused by such shifts tend to cancel each other. These unwanted voltages are substantially eliminated by equal but opposite signals induced in each of the sine and cosine windings which effects tend to cancel each other. For example, current entering terminal 81' of FIG. 2(b) travels from right-to-left along inactive conductor 78 and through each of the sections 102, 106, 110, 115, 119, and 123 to tab 141'. When the layer of FIG. 2(*a*) is superposed over the layer of FIG. 2(*b*), as shown in part in FIG. 3, tab 141' is connected to tab 141 so that the current introduced in terminal 81' travels through sections 121, 117, 113, 112, 108 and 124 thereafter returning left-to-right along inactive conductor 77 to terminal 82. Cancellation occurs, for example, between superposed inactive conductors 77 and 78 which have equal but opposite currents as explained above.

Referring to FIG. 2(*c*), a portion of a single-phase winding 126 is shown typically depicting its relative size and position with respect to the winding sections of a polyphase winding such as shown in FIG. 2(*a*). Only a portion of a single-phase winding 126 is shown since that winding is typically of greater length usually extending beneath the winding section 101 all the way to the winding section 124 and beyond.

FIG. 4 depicts a side view of a polyphase, multi-layer member 149 positioned above a single-phase member 151. The member 149 typically consists of a base 144 comprised of a relatively thick rigid material such as metal or glass. Bonded to the base 144 with an adhesive layer 145 is a first insulated layer 67', corresponding to the lower layer 67 of FIG. 2(*b*). The layer 67' is comprised of an insulating material 67'(*a*) such as Mylar clad to the conducting layer 67'(*b*), the latter of which includes the winding sections, tabs, and other conductors generally depicted in FIG. 2(*b*).

Bonded to the insulated layer 67' by adhesive layer 146 is the insulated layer 66' corresponding to the upper layer 66 of FIG. 2(*a*). The insulated layer 66', like the insulated layer 67', is further comprised of an insulating material 66'(*a*) clad to the conducting layer 66'(*b*), the latter of which includes the winding sections, tabs, and other active and inactive conductors generally depicted in FIG. 2(*a*).

Bonded to the insulated layer 66' by adhesive layer 147 is the insulated layer 68 which serves as an electro-static shield. Insulated layer 68 is comprised of an insulator 68(*a*) clad to a conducting sheet 68(*b*), where the latter is a conductor such as aluminum foil. Insulated layer 68 is of the type described in U.S. Pat. No. 3,090,934 to C. L. Farrand.

The base 144 and the attached layers 145, 67', 146, 66', 147 and 68 comprise a first member including first (66') and second (67') insulated layers of cofunction windings wherein each of the layers 66' and 67' includes a substantially equal number of winding sections of first and of second cofunction types as explained in connection with FIGS. 2(*a*) and 2(*b*). Further, each of the insulated layers 66' and 67' are positioned so that the active conductors and winding sections on one of the layers are superposed over the active conductor voids and winding section voids on the other layer.

The member 149 is positioned in close proximity to a member 151. The members 149 and 151 are separated by an air gap 150. The member 151 is comprised of a base 154 typically made of glass or metal. A suitable metal base is described in U.S. Pat. No. 3,202,948 to C. L. Farrand. Bonded to the base 154 by an adhesive layer 128 is an insulated layer 126'. The insulated layer 126' is comprised of an insulator 126'(*a*) clad to a conducting layer 126'(*b*), the latter of which is formed into a scale like the single-phase winding 126 depicted in FIG. 2(*a*).

The member 149 and the member 151 are mounted relatively movable with respect to each other and further, the windings of the insulated layers 66', 67', and 126' are inductively coupled to each other.

Although a wide variance in dimensions is possible, typical dimensions for the bases and layers of FIG. 4 are presented in the following CHART I.

CHART I

Reference No.	Dimension (Inches)
144	0.365
145	0.0005
67' (*a*)	0.002
67' (*b*)	0.001
146	0.0005
66' (*a*)	0.002
66' (*b*)	0.001
147	0.0005
68(*a*)	0.001
68(*b*)	0.001
150 (air gap)	0.005
126' (*b*)	0.001
126' (*a*)	0.002
128	0.0005
154	0.365

OPERATION

The function of the position measuring transformers previously described with reference to FIGS. 1(*a*), 1(*b*), 2(*a*), 2(*b*), 3, and 4 is to measure or indicate the relative position of two members. The two members are generally rigidly attached to relatively movable parts (not shown) of an apparatus such as a machine tool and therefore are operative to indicate the relative positions of the parts of that machine tool.

In order to measure relative position, the position measuring transformer schematically shown in FIGS. 1(*a*) and 1(*b*) has a signal applied between terminals **40** and **41** of the continuous winding **39** of FIG. 1(*b*). For such a signal applied between terminals **40** and **41**, in the member of FIG. 1(*b*), a maximum signal is induced in the FIG. 1(*a*) sine winding **18** and a minimum signal is induced in the FIG. 1(*a*) cosine winding **19**. The maximum signal is induced in sine winding **18** because each of the active conductors **−27** and **−28** for each winding section of the sine winding **18** is symmetrically positioned between two parallel active conductors **43** of continuous winding **39** so that the induced voltages in each of the active conductors **−27** and **−28** are equal and additive.

By way of comparison, each of the active conductors **−27** and **−28** of the winding sections for the cosine winding **19** are positioned such that they symmetrically straddle a single active conductor **43** of the continuous winding **39** so that the voltages induced in the active conductors **−27** and **−28** are equal but opposite so as to tend to cancel each other and produce a minimum signal.

In FIG. 1(*c*), the continuous winding **39′** is shifted relative to the sine winding **18** and the cosine winding **19** of FIG. 1(*a*) as compared with the position of the continuous winding **39** of FIG. 1(*b*). This shift of continuous winding **39′** is analogous to a shift of continuous winding **39** of FIG. 1(*b*) an amount equal to a quarter cycle of continuous winding **39** such as would occur if continuous winding **39** were attached to a moving part of a machine tool.

For a current in continuous winding **39′** of FIG. 1(*c*) between terminals **41′** and **40′**, the signal induced between terminals **20** and **21** for sine winding **18** is a minimum and the signal induced between terminals **23** and **24** for cosine winding **19** is a maximum.

When the continuous winding **39** of FIG. 1(*b*) is shifted to positions between that shown in FIG. 1(*b*) and that shown in FIG. 1(*c*), then the magnitude of the signals detected at terminals **23** and **24** and terminals **20** and **21** vary proportionately. For example, when the continuous winding **39** is half-way between the FIG. 1(*b*) position and the FIG. 1(*c*) position, the signals at terminals **23** and **24** and terminals **20** and **21** are equal. As is well known in the prior art, unique signals are generated for all relative positions of the polyphase and single-phase windings over each cycle.

While the above-described operation is typical when position measuring transformers are used as "transmitters," position measuring transformers are also frequently used as "receivers." As a receiver the transformer of FIGS. 1(*a*) and 1(*b*) may have in-phase, sinusoidal signals applied between terminals **23** and **24** and between terminals **20** and **21**. For selectable magnitudes of those input signals, a corresponding sinusoidal error signal having a magnitude which is a function of the relative position of the FIG. 1(*a*) and FIG. 1(*b*) members is generated between terminals **40** and **41**.

FURTHER AND OTHER EMBODIMENTS

FIG. **5** depicts a rotary embodiment of a multi-layered, 16-section, polyphase, and specifically two-phase, member **218**. The member **218** includes winding sections **201, 202, . . ., 216**. Those winding sections are connected into a sine winding **220** comprising winding sections **201, 203, 205, 207, 209, 211, 213**, and **215** and into a cosine winding **221** comprising winding sections **202, 204, 206, 208, 210, 212, 214**, and **216**. Similar to the convention employed with respect to FIG. 1(*a*) and FIG. **3**, the winding sections, active conductors, and inactive conductors appearing on one layer are shown as solid lines while the similar components appearing on the other layer are shown by broken lines. For example, active conductor **225**, of winding section **215**, inactive conductor **226**, connecting active conductor **225** to the winding section **201**, and winding section **201** itself, are all on one layer. In a similar manner, active conductor **228** of winding section **215** and inactive conductor **229** connecting the active conductor **228** to the winding section **203**, and the winding section **203** are all on another layer.

The cutaway view through portions of winding sections **212, 213, 214, 215**, and **216** reveals a portion of a single-phase member **232** including a continuous, single-phase winding **231**. The winding **231** is comprised of a plurality of radially extending, equally spaced, serially connected active conductors **233**. The active conductors **233** have a pitch, P′, which in the case of a rotary device is an angular measurement between active conductors. Note that in connection with FIG. 1(*b*), the pitch, P, was measured in linear distance. The winding sections of the polyphase member **218** are oriented with section spacing, S′, which is a predetermined quantity with respect to the pitch, P′, of the active conductors on a single-phase member **232**. In the case of FIG. **5**, S′ equals 1 ½ P′. Therefore, a quadrature relationship exists between the sine winding **220** and the cosine winding **221**. As discussed above in connection with FIGS. 1(*a*), 1(*b*) and 1(*c*), other spacings may be employed to achieve different phase relationships between the polyphase windings and the single-phase winding.

It should be noted in connection with FIG. **5** that winding sections associated with the sine winding **220** are interdigitated with winding sections associated with the cosine winding **221**. Similarly, an equal number of active conductors associated with the sine winding **220** appear on one layer **223** (broken) as on the other layer **224** (solid) and similarly, an equal number of active conductors associated with the cosine winding **221** appear on each of the layers **223** and **224**. Furthermore, the two layers in the polyphase member **218** have active conductors and winding sections which are superposed so that they fall adjacent the active conductor voids and winding section voids on the other layers.

In order to connect the sections on the layers of the same cofunctions type, tabs **239** and **240** are provided on layer **224** and tabs **239′** and **240′** are provided on layer **223**. A solder or other type electrical connection may then be made between tabs **239** and **239′** and between **240** and **240′**. Similarly, the terminals **243** and **244** for sine winding **220** and terminals **246** and **247** for the cosine winding **221** may include provision for through-layer connections.

FIGS. 6(*a*) and 6(*b*) depict upper layer **366** and lower layer **367**, respectively, similar to the layers depicted in FIGS. 2(*a*) and 2(*b*). The layers of FIG. 6(*a*) and FIG. 6(*b*) differ from those of FIGS. 2(*a*) and 2(*b*) in that they are without large tabs for through-layer connections and the inactive conductors interconnecting the active conductors are symmetrically placed. More particularly, typical active conductors **357, 357′, 357″** and **357‴** in FIG. **6** are analogous to the active conductors **−58** in FIGS. 2(*a*) and 2(*b*). Similarly, the end active conductors **358**(*a*) and **358′**(*a*) on upper layer **366** and the end active conductors **358**(*b*) and **358′**(*b*) are similar to the end active conductors in FIGS. 2(*a*) and 2(*b*). The active conductors **358**(*a*) and **358**(*b*) do not terminate, however, in a large tab but instead terminate in an inactive conductor **359**(*a*) and **359**(*b*) which also are employed to make a through-layer connection. In a similar manner, the active conductor **361** in upper layer **366** does not terminate in a large tab (like tab **141** in FIG. 2(*a*)) but merely extends long enough to overlay the end of active conductor **358** in the lower layer **367**, when the upper layer **366** is overlayed that lower layer **367**. The reason that the tabs and other irregularities in the inactive conductors of FIG. 2(*a*) and 2(*b*) have been eliminated in the FIG. **6** embodiment is apparent after reference to FIG. **7**.

In FIG. **7**, the relatively movable member **325** includes a polyphase winding **328**, comprised of the upper layer **366** of FIG. 6(*a*) and the lower layer **367** of 6(*b*), mounted on the underside of a base **320**. The member **325** is depicted showing its position above a relatively movable member **332**. The member **332** includes single-phase winding **326** having active conductors like typical active conductors **330, 330′** and **330″** which are greater in length than the typical active conductors **357, 357′** and so on of the polyphase windings **328**. Since the

active conductors such as typical active conductor **330** are greater in length, it is important that no unwanted conductor area be provided by polyphase windings **328** which would inductively couple those active conductors since any such area would generate unwanted error signals. The polyphase member **325** having polyphase windings **328** is absent tabs and other irregularities and therefore does not generate unwanted error signals. Additionally, polyphase windings **328** may be used with the single-phase winding **126** of FIG. **2**(*c*) where the active conductors **351** are shorter than the active conductors of FIG. **7**. Polyphase members comprised of layers like those shown in FIGS. **2**(*a*) and **2**(*b*), however, are not desirably used with members having active conductors of a length like that of active conductor **330**, which length is shorter than the length of active conductors **–58** in FIG. **2**(*a*) and **2**(*b*), because of the unwanted tab and other uncompensated conductive areas from which unwanted inductive coupling is likely to result.

While the winding sections in all of the polyphase windings described in connection with all of the embodiments herebefore have been depicted as including two coupling conductors per section, any number of coupling conductors per section may be employed within the spirit of the present invention. Accordingly, for the purposes of this specification, the term "-winding section" or more simply "section" is defined to mean a portion of a transformer winding which, when interconnected with other sections, forms a complete transformer winding. Sections are generally comprised of one or more active conductors physically disposed on a member so that, when another member is positioned in close proximity thereto, those active conductors inductively couple active conductors on that other member. When there are two active conductors per section, the sections are frequently called U bar sections. When there are four active conductors per section, the sections are frequently called W bar sections.

The W bar sections, of course, include two central active conductors and two outside active conductors totalling four active conductors. Referring to FIG. **1**(*a*), for example, each of the sections **1** through **16** can be replaced by W bar sections. In making that replacement, the section spacing, S, is conveniently measured from a line equally spaced between the two central active conductors of the W bar sections.

With a substitution of the W bar or other type sections for the U bar sections of FIG. **1**(*a*), it should be noted that across-the-winding placement of terminals or tabs from top to bottom margins are achieved by placing the active conductors of a single section on different layers in the same manner as across-the-winding placements were achieved with winding section **1** and winding section **16** of FIG. **1**(*a*) as previously discussed. More particularly, a W bar section is essentially two U bar sections. Therefore, any one of the component U bar sections within a W bar section may be formed with an active conductor from each layer in the same manner as the winding sections **1** and **16** of FIG. **1**(*a*). By forming sections with active conductors on different layers, across-the-winding connections are readily made.

While FIG. **4** depicts one multi-layer member, the present invention also encompasses many different variations. For example, the insulated layers **66'** and **67'** in FIG. **4**, have been indicated as comprised of conducting layers **66'** (*b*) and **67'** (*b*) each clad to an insulated layer **66'** (*a*) and **67'** (*a*), respectively. Alternatively, one single insulated layer such as Mylar or other plastic may be employed with a conducting layer clad to either side thereof. Other similar variations are, of course, possible.

While the invention generally includes active conductors superposed over active conductor voids in a multi-layered structure, the active conductor voids may actually be filled with conductors which are identical to active conductors except that they are not connected on both ends and accordingly cannot conduct electricity. These unconnected conductors may be useful as mechanical supports without affecting the electrical characteristics of the position measuring transformer.

Although the invention has been described with respect to a-c signals and electromagnetic energy transfers (transformer action), the invention also encompasses d-c energization and/or electrostatic energy transfers (capacitor action).

While the invention has been particularly shown and described with reference to preferred embodiments thereof it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and the scope of the invention.

What is claimed is:

1. A position measuring device comprising, a first relatively movable member including first and second layers of cofunction windings wherein each layer includes a substantially equal number of active conductors forming winding sections of first and of second cofunction types, wherein each layer includes winding sections separated by winding section voids, said voids in each layer being characterized by the absence of active conductors, and wherein said first layer is superposed over said second layer so that each winding section on each layer is superposed with a corresponding winding section void on the other layer, and

a second relatively movable member having a winding electrically related to said cofunction windings.

2. A winding member for a position measuring transformer comprising first and second layers of cofunction windings, each of said layers including a substantially equal number of active conductors, said active conductors forming winding sections of first and of second cofunction types, each of said layers including active conductors separated by active conductor voids, said voids in each layer characterized by the absence of active conductors, wherein said first layer is superposed over said second layer so that each winding section on each layer is superposed with a corresponding winding section void on the other layer.

3. The member of claim **2** wherein at least some of said winding sections are formed with active conductors from each of said layers.

4. The member of claim **2** wherein said active conductors are printed on an insulated layer and wherein said active conductors are connected into winding sections by printed inactive conductors.

5. The member of claim **2** wherein the number of active conductors forming said winding sections of said first cofunction type equals the number of active conductors forming said winding sections of said second cofunction type.

6. A winding member for a position measuring transformer comprising,

a first layer having first active conductors connected to form first winding sections appearing substantially at selected intervals of a first plurality of periodic intervals and having second active conductors connected to form second winding sections appearing substantially at selected intervals of a second plurality of periodic intervals, at least some of said first and second active conductors separated by active conductor voids,

a second layer having third active conductors connected to form third winding sections appearing substantially at selected intervals of said first plurality of periodic intervals and having fourth active conductors connected to form fourth winding sections appearing substantially at selected intervals of said secondplurality of periodic intervals, at least some of said third and fourth active conductors separated by active conductor voids, said first, second, third, and fourth winding sections being of the cofunction type with winding sections of each layer separated by winding section voids, said voids being characterized by the absence of active conductors, and wherein said first layer is superposed over said second layer so that each winding section on each layer is superposed with a corresponding winding section void on the other layer,

insulating means securing said first and second layers together to form a composite layer wherein said first and

third winding sections are interdigitated with said second and fourth winding sections and wherein each of said first, second, third and fourth active conductors is disposed in an array each terminating with one end in a first direction thereby forming a first margin on said layers and each terminating with an opposite end in an opposite second direction thereby forming a second margin on said layers, said member further including,

first inactive conductors for interconnecting said first winding sections along said first margin on said first layer,

second inactive conductors for interconnecting said second winding sections along said second margin of said first layer,

third inactive conductors, superposed over said first inactive conductors, for interconnecting said third winding sections along said first margin on said second layer,

fourth inactive conductors, superposed over said second inactive conductors, for interconnecting said fourth winding sections along said second margin on said second layer, and

means connecting said first and third inactive conductors and means connecting said second and fourth inactive conductors so as to cause current in said first inactive conductors to be opposite in direction to the current in said third inactive conductors, and so as to cause current in said second inactive conductors to be opposite in direction to the current in said fourth inactive conductors whereby unwanted inductive fields from said first and third inactive conductors tend to cancel and whereby unwanted inductive fields from said second and fourth inactive conductors tend to cancel.

7. In a position measuring transformer having a pair of relatively movable transformer members,

one of said members comprising first and second layers,

each of said layers having interspaced first and second groups of active conductors thereon, forming winding sections of first and of second cofunction types wherein each layer includes winding section voids, said voids being characterized by the absence of active conductors, and wherein said first layer is superposed over said second layer so that each winding section on each layer is superposed with a corresponding winding section void on the other layer,

said active conductors extending at least substantially transversely of the direction of relative movement of said members,

the groups of said first layer being interspaced with the groups of said second layer to form an array,

means including first circuit conductors extending on one side of said array on each of said layers connecting said first groups on the corresponding layer in a first series circuit,

first connecting means connecting said first series circuit on said first layer to said first series circuit on said second layer,

means including second circuit conductors on the opposite side of said array on each of said layers connecting said second groups on the corresponding layer in a series circuit, and

second connecting means connecting said second series circuit on said first layer to said second series circuit on said second layer.

8. A transformer member according to claim 7 wherein said circuit conductors extend along said array and out of inductive coupling relation to said active conductors.

9. A transformer member according to claim 8 wherein said active conductors and said circuit conductors in each of said layers comprise continuous printed circuit elements.

10. A transformer member according to claim 7 wherein said first groups form a first winding and said second groups form a second winding in quadrature relation to said first winding.

11. A transformer member according to claim 7 wherein said first circuit conductors in said first layer extend in inductive coupling relation to said first circuit conductors in said second layer,

said first circuit conductors in said first layer being effective to carry current in a direction opposite to the current carried by said first circuit conductors in said second layer and wherein said second circuit conductors in said first layer extend in inductive coupling relation to said second circuit connectors in said second layer,

said second circuit connectors in said first layer being effective to carry current in a direction opposite the current carried by said second circuit connectors in said second layer.

12. A transformer member according to claim 7 wherein said groups are spaced from each other in interdigitized relation and are arranged in two similar patterns on opposite sides of a center line.

13. A transformer according to claim 7 wherein the terminal groups of said array each comprises an active conductor in said first layer and an active conductor in said second layer.

14. A transformer member according to claim 7 wherein the terminal group at one end of said array comprises an active conductor in said first layer and an active conductor in said second layer,

said first conducting means connecting said last two mentioned active conductors at adjacent ends thereof,

and wherein the terminal group at the opposite end of said array comprises an active conductor in said first layer and an active conductor in said second layer,

said second conducting means connecting said last two mentioned active conductors at adjacent ends thereof.

15. A position measuring transformer comprising relatively movable transformer members, one of said members having windings of the cofunction type, each winding having a first portion thereof arranged in a first layer and a second portion juxtaposed therewith in a second layer, separate means for connecting the portions of each significance in series,

said first portions each comprising sections of active conductors having means in said first layer connecting consecutive sections in series,

said second portions each comprising sections of active conductors having means in said second layer connecting consecutive sections in series, said sections in said first and second layers being of the first and second cofunction type, each of said layers having voids between each of the sections, said voids having no active conductors therein, said first layer being superposed over said second layer so that each winding section on each layer is superposed with a corresponding winding section void on the other layer,

another of said transformer members having a cofunction winding inductively related to said windings of.

16. A position measuring transformer comprising relatively movable transformer members, one of said members having sine and cosine windings each having a first portion thereof arranged in a first layer and a second portion juxtaposed therewith in a second layer, separate means for connecting the sine portions and cosine portions, respectively, in series,

said first sine and cosine winding portions each comprising staggered sections of active conductors having means in said first layer connecting consecutive sections in series,

said second sine and cosine winding portions each comprising staggered sections of active conductors having means in said second layer connecting consecutive sections in series, each of said layers having voids between each of the sections, said voids having no active conductors therein, said first layer being superposed over said second layer so that each winding section on each layer is superposed with a corresponding winding section void on the other layer,

another of said transformer members having a winding inductively related to said sine and cosine windings.

17. A transformer according to claim 16, said sections of the sine and cosine winding portions of each layer having spaces juxtaposed with said sections of the sine and cosine winding portions of the other layer.

18. A transformer according to claim 16, wherein consecutive sine sections and consecutive cosine sections of each layer are each spaced apart providing spaces therebetween, each space juxtaposed with both a sine section and a cosine section of the other layer.

19. A transformer according to claim 16, wherein consecutive sine sections of one layer are spaced apart providing a space, one portion of said space containing a cosine section of that layer and another portion of said space being juxtaposed with both sine and cosine sections of the other layer, and wherein

consecutive cosine sections of said one layer being spaced apart providing a space, one portion of said last-mentioned space containing a sine section of said one layer and another portion of said last-mentioned space being juxtaposed with both sine and cosine sections of said other layer.

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