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Del Vecchio et al.

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[54] **ROTATING FLUX TRANSFORMER**

[75] Inventors: **Robert M. Del Vecchio**, Sunnyvale, Calif.; **Theodore R. Specht**, Sharon, Pa.

[73] Assignee: **Westinghouse Electric Corp.**, Pittsburgh, Pa.

[21] Appl. No.: **807,147**

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[51] **Int. Cl.**[4] **H02J 1/00;** H01H 85/02

[52] **U.S. Cl.** **307/83;** 307/415; 307/106; 336/229; 336/5; 336/10; 336/12; 323/215; 323/250; 323/251; 363/154

[58] **Field of Search** 307/83, 106, 412, 413, 307/414, 415, 416, 417, 418, 419, 420, 421, 422; 336/220, 221, 225, 229, 206, 208, 184, 155, 130, 233, 234, 178, 195, 5, 10, 12; 376/128, 140, 135, 142, 134, 146, 136, 132, 133, 130; 363/154; 323/215, 200, 251, 301, 332, 331, 355, 305, 328, 329

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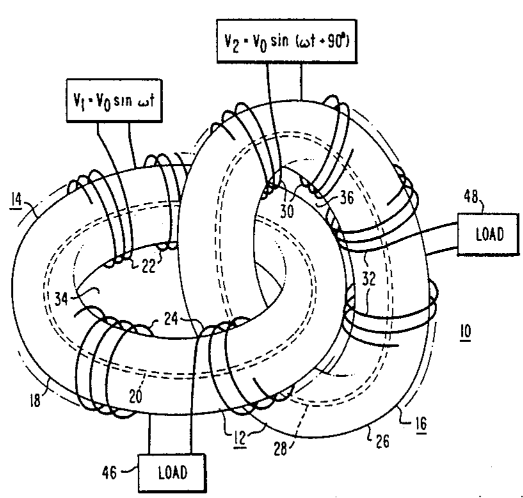
Primary Examiner—Bernard Roskoski
Assistant Examiner—Shik Luen Paul Ip
Attorney, Agent, or Firm—D. R. Lackey

[57] **ABSTRACT**

A rotating flux transformer having at least two magnetic cores, each in the form of a torus, with each magnetic core having poloidal and toroidal windings. The need for breaking the torus and bringing out leads from the poloidal winding is eliminated by passing each torus through the core window of the remaining torus, or tori. Each poloidal winding is shorted, with the toroidal winding, or windings, of the other magnetic core or cores, inducing an excitation voltage into each shorted poloidal winding which is 90° out of phase with the voltage applied to the toroidal winding on the same magnetic core.

17 Claims, 12 Drawing Figures



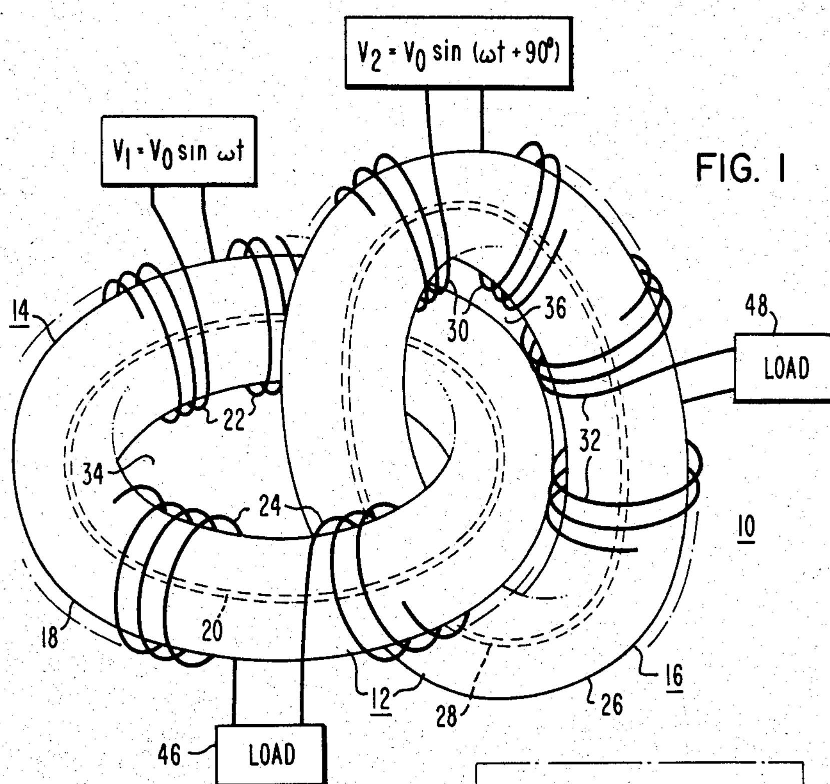

V1 = V0 sin ωt
V2 = V0 sin (ωt + 90°)
14
22
34
24
20
18
12
28
26
16
30
36
32
10
48
LOAD
46
LOAD

FIG. 1

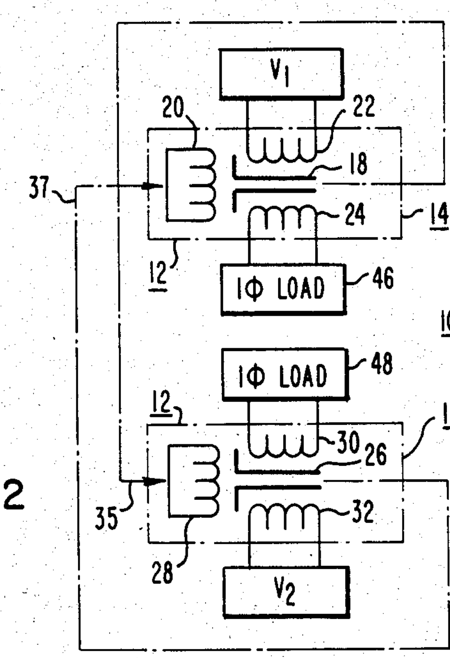

V1
20
22
18
37
24
14
12
1Φ LOAD
46
10
1Φ LOAD
48
12
16
30
26
35
32
28
V2

FIG. 2

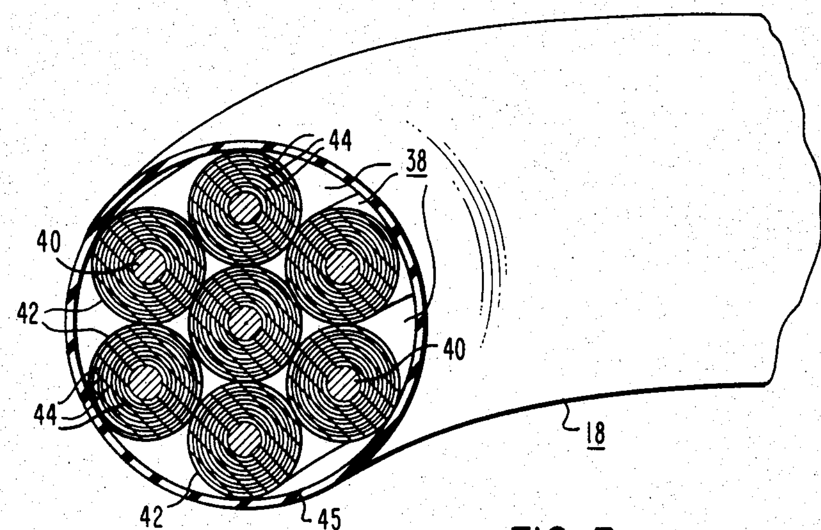

44
38
40
42
40
44
18
42
45

FIG. 3

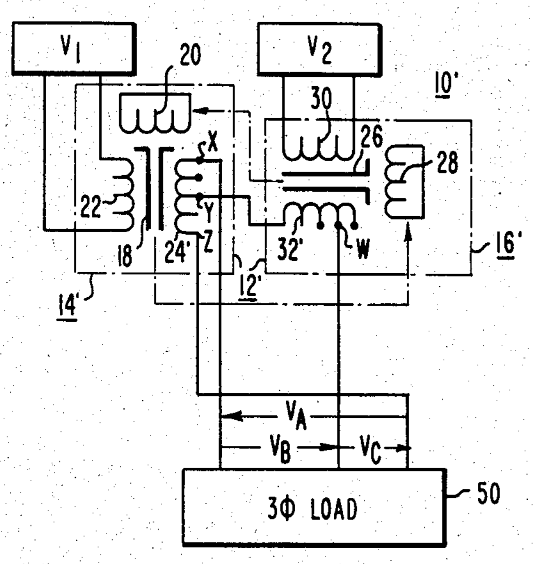

V_1
20
V_2
10'
30
26
28
X
22
Y
Z
18
24'
32'
W
16'
12'
14'
V_A
V_B
V_C
3Φ LOAD
50

FIG. 4

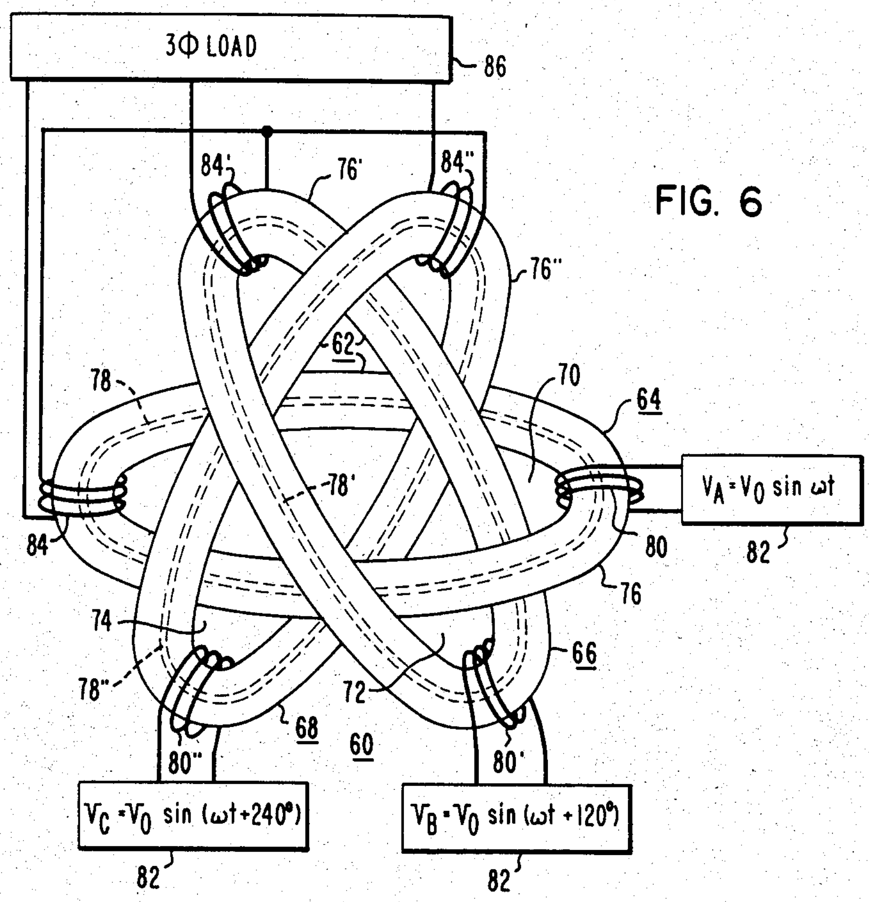


FIG. 6

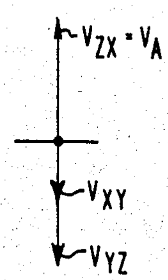


FIG. 5A

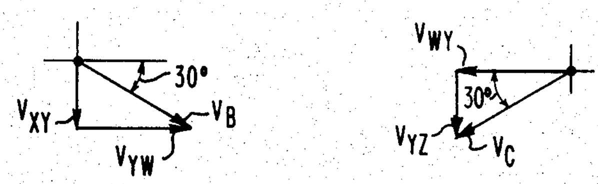


FIG. 5B

FIG. 5C

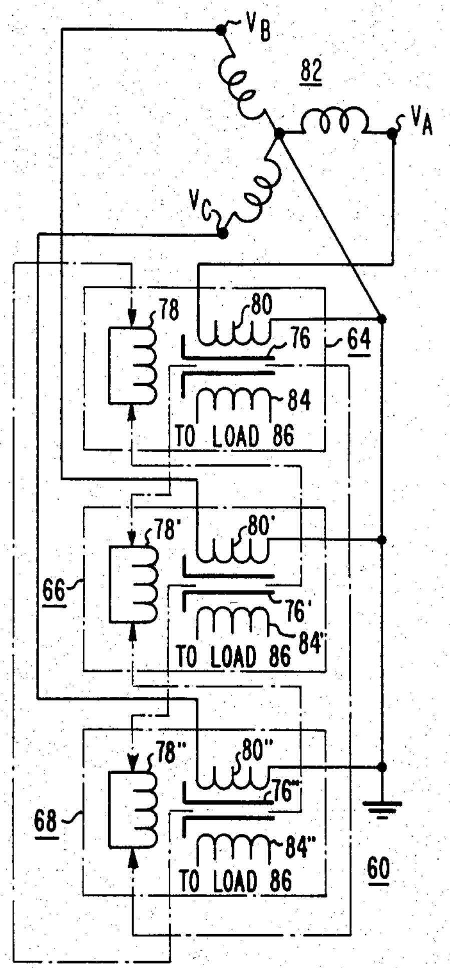


FIG. 7

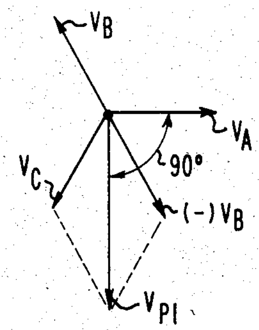


FIG. 8A

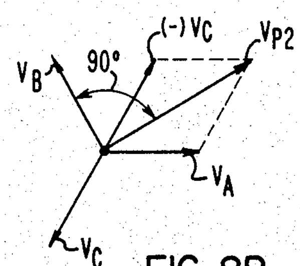


FIG. 8B

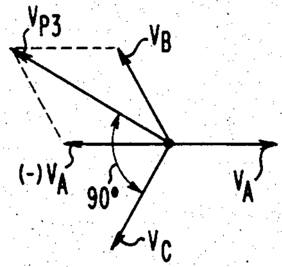


FIG. 8C

ROTATING FLUX TRANSFORMER

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates in general to electrical transformers, and more specifically to electrical transformers in which the vector sum of the magnetic flux produced in the magnetic core creates a rotating induction vector.

2. Description of the Prior Art

Co-pending application Ser. No. 607,852, filed May 7, 1984, entitled "Low Core Loss Rotating Flux Transformer", which is assigned to the same assignee as the present application, discloses a transformer construction in which a rotating induction vector is produced in the entire magnetic core. The magnetic core is in the form of a torus, with both toroidal and poloidal windings generating phase displaced alternating flux which is added vectorially to create the rotating induction vector. By providing sufficient exciting current to produce a saturated rotating induction vector, hysteresis losses are reduced to zero. When the magnetic core is constructed of an amorphous alloy, which is nominally about 1 mil thick, a magnetic core with unusually low core losses is produced, as the magnetic domains of a magnetic material disappear at saturation, further reducing the already low eddy current losses of an amorphous magnetic core. Application Ser. No. 607,852 is hereby incorporated into the specification of the present application by reference.

SUMMARY OF THE INVENTION

Briefly, the present invention is a new and improved rotating flux transformer which utilizes at least two mutually intersecting tori. Each torus magnetic core includes poloidal and toroidal windings, with each magnetic core passing through the opening of the remaining magnetic core, or cores. Each poloidal winding includes shorted turns. A voltage is induced into each shorted poloidal winding by the toroidal winding of the intersecting torus, or tori. Thus, the invention eliminates the need of bringing leads out from the poloidal windings.

Alternating voltages having predetermined phase differences are applied to the toroidal windings, such that the induced poloidal voltage in each poloidal winding is 90° out of phase with the toroidal voltage of the same magnetic core. The excitation currents provided in the poloidal and toroidal windings of each magnetic core are tailored to produce a saturated rotating induction vector. The poloidal windings only provide excitation current. Load currents are provided only by the easily cooled toroidal windings.

In a two tori embodiment, the voltages applied to the two toroidal primary windings are 90° out of phase. Toroidal secondary windings produce a two-phase output, which may be converted to a three-phase output by using the two-to-three phase Scott connection.

In a three tori embodiment, a three-phase voltage source is utilized, i.e., the three primary voltages applied to the three toroidal primary windings are 120 electrical degrees apart, and the output voltage provided by the toroidal secondary windings is also three-phase. The 90° phase difference required to produce the rotating induction vector in each torus core, is developed from the other two-phase voltages.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may be better understood, and further advantages and uses thereof more readily apparent, when considered in view of the following detailed description of exemplary embodiments, taken with the accompanying drawings in which:

FIG. **1** is a perspective view of a core-coil assembly of a rotating flux transformer constructed according to the teachings of the invention;

FIG. **2** is a schematic diagram of the rotating flux transformer shown in FIG. **1**;

FIG. **3** is a fragmentary, perspective view, in section, of one of the magnetic cores shown in FIG. **1**;

FIG. **4** is a schematic diagram illustrating a two-to-three phase embodiment of the transformer shown in FIG. **1**;

FIGS. **5**A, **5**B and **5**C are phasor diagrams which illustrate how the three output phases of the FIG. **4** embodiment are generated;

FIG. **6** is a perspective view of a core-coil assembly of a rotating flux transformer constructed according to another embodiment of the invention;

FIG. **7** is a schematic diagram of the rotating flux transformer shown in FIG. **6**; and

FIGS. **8**A, **8**B and **8**C are phasor diagrams which illustrate how the induced voltages in the poloidal windings are generated to provide the desired 90° phase shift relative to the voltage applied to the toroidal primary winding on the same magnetic core.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to the drawings, and to FIGS. **1** and **2** in particular, there is shown a perspective view and a schematic diagram, respectively, of a rotating flux transformer **10** constructed according to a first embodiment of the invention. Transformer **10** comprises a core-coil assembly **12** which includes first and second tori **14** and **16**, respectively. The first torus **14** includes a magnetic core **18** in the form of a torus, a poloidal winding **20**, a toroidal primary winding **22**, and a toroidal secondary winding **24**. In like manner, the second torus **16** includes a magnetic core **26** in the form of a torus, a poloidal winding **28**, a toroidal primary winding **30** and a toroidal secondary winding **32**.

In order to eliminate the need for electrical leads on the poloidal windings **20** and **28**, each poloidal winding is shorted, and an excitation voltage is induced into each poloidal winding by constructing tori **14** and **16** to intersect one another. In other words, tori **14** and **16** have core openings or windows **34** and **36**, respectively, with the first torus **14** linking window **36** of the second torus **16**, and with the second torus **16** linking the window **34** of the first torus **14**. Thus, while the poloidal and toroidal windings of the same torus are non-inductive, the toroidal primary winding of one torus is in inductive relation with the poloidal winding of the other torus, and a voltage will thus be induced into each poloidal winding. Broken lines **35** and **37** in FIG. **2** indicate the inductive links between tori **14** and **16**.

In order to generate magnetic flux in each magnetic core which, when added vectorially, will produce a rotating induction vector, the fluxes produced by the poloidal winding and toroidal primary winding of a torus must be about 90 electrical degrees out of phase. The desired result may thus be achieved by connecting toroidal primary windings **22** and **32** of tori **14** and **16**, respectively, to sources V_1 and V_2, respectively, of alternating potential. Source V_1 is a sine wave of a predetermined frequency, represented by $V_0 \sin \omega t$ and V_2 is a sine wave of like frequency represented by $V_0 \sin (\omega t + 90°)$. The predetermined frequency may be 60 Hertz, for example. Thus, the magnetic fluxes produced in magnetic cores **18** and **26** by their associated toroidal and poloidal windings will be 90° out of phase, producing a rotating induction vector.

In order to achieve the objective of reducing core losses, however, it is not sufficient that the resulting induction vector rotate. The excitation current produced by the associated poloidal and toroidal windings must produce a saturated rotating induction vector, in order to eliminate hysteresis losses. Both flux components produced by the poloidal and toroidal windings must saturate their associated core areas in order to produce a saturated rotating induction vector. If the magnetic core, such as magnetic core **18** of the first torus **14**, were to have a single axially extending central opening with a shorted poloidal winding comprising a single shorted coil of one or more turns, the flux induced by the poloidal winding will not be sufficient to saturate the associated flux carrying volume of the magnetic core. This is due to the fact that the flux carrying volume associated with the poloidal winding is larger than the flux carrying volume associated with the toroidal primary winding, for reasonably configured tori. The induced poloidal winding current generates flux in the associated magnetic core which is opposite to the driving flux. This opposing flux must thus be sufficient to saturate the associated core volume, and the driving flux must be of sufficient strength to exceed the saturating opposing flux. Since the flux carrying volume associated with the poloidal winding exceeds the flux carrying volume associated with the toroidal primary winding, at saturation the induced flux would have to be greater than the driving flux, which is not possible. This problem is overcome by the teachings of the invention, as shown in FIG. 3.

More specifically, FIG. **3** is a fragmentary, perspective view, in section, of one of the magnetic cores **18** or **26**, such as magnetic core **18**, for example. Both magnetic cores **18** and **26** are of like construction. The torus is subdivided into a plurality of subtori **38**. Each subtorus **38** includes a central coil **40** comprising one or more shorted turns of electrical conductor, such as copper or aluminum, for example. Each central coil **40** is surrounded by a magnetic core **42**. As illustrated, each magnetic core **42** may have a plurality of core wraps or laminations **44** of a suitable magnetic material. In a preferred embodiment of the invention, laminations **42** are formed of an amorphous alloy. However, other magnetic materials may be used, such as the ferrites. If magnetic core **42** is constructed of an amorphous alloy, a strip of amorphous alloy, which is typically about 1 mil thick, and 4 to 6 inches wide, may be spirally wound about a preformed poloidal coil **40**, with the winding proceeding about the shorted coil loop until the desired core build is achieved.

With the subcore arrangement shown in FIG. 3, the flux induced into each subcore **42** opposes the driving flux for only itself, and does not affect the other subcores **42**. The volume of each subcore **42** is thus selected for the excitation which will be provided by each coil **40**, enabling each subcore **42** to saturate due to the induced current in its associated shorted coil **40**. The subcores **42** may be held in assembled relation by any suitable outer wrap **45**, which may provide the ground insulation about which the toroidal windings may be wound.

The toroidal secondary windings **24** and **32** may each be connected to a separate load circuit **46** and **48**, respectively, i.e., to single phase loads; or, they may be connected to a two-phase load, as desired. It is also practical to construct the toroidal secondary windings **24** and **32** with 50% and 86.6% taps, and connect the tori **14** and **16** as main and teaser transformers, respectively, in the Scott two-phase to three-phase configuration. Tori **14** and **16** may also be specifically constructed as main and teaser transformers, if desired, requiring only a center tap on the secondary winding of the main transformer.

A transformer arrangement using two similar tori with 50% and 86.6% taps on each toroidal secondary winding, is shown in FIG. **4**, which is a schematic diagram of a transformer **10'**. Transformer **10'** provides a three-phase output V_A, V_B and V_C from the 90° phase displaced primary or input voltages V_1 and V_2. Output voltages V_A, V_B and V_C may be connected to a three-phase load **50**. Components in FIG. **4** which are the same as those shown in FIGS. **1** and **2** are given like reference numerals and will not be described again. Components in FIG. **4** which are similar to those of FIG. **1** except modified in some way, are given the same reference numeral along with a prime mark.

More specifically, transformer **10'** includes a first torus **14'** which has a toroidal secondary winding **24'** having ends x and z and a center tap y. Transformer **10'** also includes a second torus **16'** which has a toroidal secondary winding **32'** having one end connected to the center tap y on winding **24'**, and an 86.6% tap w. Voltage V_A is the potential of x with respect to z (V_{zx}); voltage V_B is the potential of ω with respect to x (V_{xw}); and voltage V_C is the potential of z with respect to ω (V_{wz}). FIG. **5**A is a phasor diagram which illustrates voltage V_A being produced by the vector summation of voltages V_{xy} and V_{yz}. FIG. **5**B is a phasor diagram which illustrates voltage V_B being produced by the vector summation of voltages V_{yw} and V_{xy}, which voltages are 90° out of phase. FIG. **5**C is a phasor diagram which illustrates voltage V_C being produced by the vector summation of voltages V_{yz} and V_{wy}, which voltages are 90° out of phase. Since voltage C_{xy} is 50% of the total secondary voltage, and voltages V_{yw} and V_{wy} are each 86.6% of the total secondary voltage, voltage V_B lags V_A by 120°, and voltage V_C leads voltage V_A by 120°.

FIG. **6** is a perspective view of a transformer **60** which is a true three-phase embodiment of the invention. Transformer **60** includes a core-coil assembly **62** which includes first, second and third mutually intersecting tori **64**, **66** and **68**. In other words, tori **64**, **66** and **68** have core windows **70**, **72** and **74**, respectively, with torus **64** linking tori **66** and **68** via their windows **72** and **74**, torus **66** linking tori **64** and **68** via their windows **70** and **74**, and torus **68** linking tori **64** and **66** via their windows **70** and **72**. Torus **64** includes a magnetic core **76** which is constructed of a plurality of subtori, as shown in FIG. **3**, a shorted poloidal winding **78**, a toroidal primary winding **80** connected to voltage V_A of a three-phase source **82**, such as the secondary winding of a three-phase transformer, and a toroidal secondary winding **84**. Tori **66** and **68** are constructed in the same manner as torus **64**, and like reference numerals are used to identify like components, except for the addition of a single prime mark relative to torus **66**, and a double prime mark relative to torus **68**. The three toroidal primary windings **80**, **80'** and **80''** are connected to a three-phase voltage represented by voltages V_A, V_B and V_C. If voltage V_A is a sine wave equal to $V_o \sin \omega t$, voltage V_B may be represented by $\sin(\omega t+120°)$ and voltage V_C may be represented by $V_o \sin(\omega t+240°)$. The toroidal secondary windings **84**, **84'** and **84''** are connected to a three-phase load **86**.

Tori **64**, **66** and **68** are linked such that the voltage induced in each poloidal winding is 90° out of phase with the voltage applied to the toroidal primary winding on the same magnetic core. FIG. **8A** is a phasor diagram which illustrates the induced poloidal voltage V_{P1} being formed from the vector summation of voltages V_C and $(-)V_B$. It will be noted that voltage V_{P1} is 90° out of phase with voltage V_A. In like manner, FIG. **8B** is a phasor diagram which illustrates the induced poloidal voltage V_{P2} being formed from the vector summation of voltages V_A and $(-)V_C$. FIG. **8C** is a phasor diagram which illustrates the induced poloidal voltage V_{P3} being formed from the vector summation $(-)V_A$ and V_B.

In summary, there has been disclosed new and improved rotating flux transformers which have at least two mutually intersecting tori. Each tori includes a shorted poloidal winding comprising a plurality of shorted coils, each of which are surrounded by a magnetic subcore. The poloidal winding, being shorted, requires no electrical leads, and thus the torus need not be broken. Breaks in the torus are to be avoided, since these breaks increase the reluctance of the flux path and would require higher excitation currents. Further, only sufficient excitation current is induced into the poloidal winding by the remaining torus or tori to saturate the associated magnetic core. Since the poloidal winding carries no load current, it is much easier to cool and breaks in the torus for cooling channels are also avoided. The 90° phase shift between the fluxes produced in a magnetic core by poloidal and toroidal windings, required to produce a rotating induction vector, is achieved in a two tori embodiment by using two alternating input voltages which are phase displaced by 90 electrical degrees. In a three tori embodiment, this result is achieved by using a three-phase voltage source.

We claim as our invention:

1. An electrical transformer, comprising:

first and second magnetic cores,

each of said first and second magnetic cores being a closed loop which defines a core window, with each magnetic core having an outer surface surrounding a longitudinal axis and a continuous axially extending opening,

first and second shorted poloidal windings disposed in the axially extending openings of said first and second magnetic cores, respectively,

first and second toroidal primary windings disposed about the outer surfaces of said first and second magnetic cores, respectively,

first and second sources of alternating potential connected to said first and second toroidal primary windings, respectively, with said first and second sources of alterating potential having like frequencies which are phase displaced by about 90 electrical degrees,

and a first toroidal secondary winding disposed in inductive relation with a selected one of said first and second toroidal primary windings,

said first and second magnetic cores being linked, with each magnetic core passing through the window of the other magnetic core, to induce a voltage in each of said first and second shorted poloidal windings which is 90° out of phase with the voltages applied to the first and second toroidal primary windings, respectively,

wherein the magnetic fluxes in each magnetic core due to the toroidal primary winding and shorted poloidal winding produce a rotating induction vector.

2. The electrical transformer of claim **1** wherein the first toroidal secondary winding is disposed in inductive relation with the first toroidal primary winding, and including a second toroidal secondary winding disposed in inductive relation with the second toroidal primary winding.

3. The electrical transformer of claim **2** wherein the first and second toroidal secondary windings are connected to provide a three-phase output voltage.

4. The electrical transformer of claim **1** wherein the first and second shorted poloidal windings each include a plurality of independent coils, with each independent coil being shorted.

5. The electrical transformer of claim **1** wherein the first and second magnetic cores each include a plurality of separate axially extending openings, and the first and second shorted poloidal windings each include a plurality of independent shorted coils, each disposed in one of said axially extending openings.

6. The electrical transformer of claim **1** wherein the excitation current generated in each of the first and second magnetic cores by the first and second sources of alternating potential applied to the first and second primary toroidal windings, and by the voltages induced into the first and second poloidal windings, causes the first and second magnetic cores to be saturated by the resulting rotating induction vector.

7. The electrical transformer of claim **1** wherein each of the first and second magnetic cores is formed of an amorphous alloy.

8. The electrical transformer of claim **1** wherein the first and second magnetic cores each include a plurality of subcores, with each of the subcores defining an axially extending opening, and the first and second shorted poloidal windings each include a plurality of independent shorted coils, with each independent shorted coil being disposed in an opening of a different subcore.

9. The electrical transformer of claim **8** wherein each subcore is formed of an amorphous alloy.

10. An electrical transformer, comprising:

first, second and third magnetic cores,

each of said first, second and third magnetic cores being a closed loop which defines a core window, with each magnetic core having an outer surface surrounding a longitudinal axis and a continuous axially extending opening,

first, second and third shorted poloidal windings disposed in the axially extending openings of said first, second and third magnetic cores, respectively,

first, second and third toroidal primary windings disposed about the outer surfaces of said first, second and third magnetic cores, respectively,

a three-phase source of alternating potential having first, second and third voltages connected to said first, second and third toroidal primary windings, respectively, and first, second and third toroidal secondary windings disposed in inductive relation with said first, second and third toroidal primary windings, respectively,

said first, second and third magnetic cores being mutually linked, with each magnetic core passing through the windows of the other two magnetic cores, to induce a voltage in each of said first, second and third shorted poloidal windings which is 90° out of phase with the voltages applied to the first, second and third toroidal primary windings, respectively,

wherein the magnetic fluxes in each magnetic core, due to the toroidal primary winding and shorted poloidal winding produce a rotating induction vector.

11. The electrical transformer of claim **10** wherein the first, second and third shorted poloidal windings each include a plurality of independent coils, with each independent coil being shorted.

12. The electrical transformer of claim **10** wherein the first, second and third magnetic cores each include a plurality of separate axially extending openings, and the first, second and third shorted poloidal windings each include a plurality of independent shorted cells each disposed in one of the separate axially extending openings.

13. The electrical transformer of claim **10** wherein the excitation current generated in each of the first, second and third magnetic cores by the first, second and third source voltages applied to the first, second and third primary toroidal windings, and by the voltages induced into the first, second and third poloidal windings, causes the first, second and third magnetic cores to be saturated by the resulting rotating induction vectors.

14. The electrical transformer of claim **10** wherein each of the first, second and third magnetic cores is formed of an amorphous alloy.

15. The electrical transformer of claim **10** wherein the first, second and third magnetic cores each include a plurality of subcores, with each subcore defining an axially extending opening, and the first, second and third shorted poloidal windings each include a plurality of independent shorted coils, with each independent shorted coil being disposed in an opening of a different subcore.

16. The electrical transformer of claim **15** wherein each subcore is formed of an amorphous alloy.

17. An electrical transformer comprising:

at least first and second magnetic cores,

each of said at least first and second magnetic cores being a closed loop which defines a core window, with each magnetic core having an outer surface surrounding a longitudinal axis and a continuous axially extending opening,

a shorted poloidal winding disposed in the axially extending opening of each of said at least first and second magnetic cores,

a toroidal primary winding disposed about the outer surface of each of said at least first and second magnetic cores,

a source of alternating potential connected to each of said at least first and second toroidal primary windings, with the sources of alternating potential having like frequencies which are phase displaced by a predetermined number of electrical degrees,

at least one toroidal secondary winding disposed in inductive relation with a selected one of the toroidal primary windings,

said at least first and second magnetic cores being linked with one another, with each magnetic core passing through the core window of each remaining magnetic core, to induce a voltage in each shorted poloidal winding which is 90° out of phase with the voltage applied to the associated toroidal primary winding on the same magnetic core,

wherein the magnetic fluxes in each magnetic core due to the toroidal primary winding and shorted poloidal winding produce a rotating induction vector.

* * * * *