# United States Patent [19]

**Bernard**

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[54] **TOROIDAL TRANSFORMER WITH INTEGRATED SELF-INDUCTANCE DEVICE**


[75] Inventor: **Chappel Bernard,** Albertville, France

[73] Assignee: **Societe Pour L'Application de L'Optique et de L'Electronique a La Recherche et a L'Automatisation Optelec, societe anonyme,** France



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[30] **Foreign Application Priority Data**

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[52] **U.S. Cl.** ................................. **336/84 C;** 336/178; 336/198; 336/212; 336/229

[58] **Field of Search** ................ 336/84 C, 84 R, 84 M, 336/212, 229, 178, 165, 155, 60, 196, 198, 134



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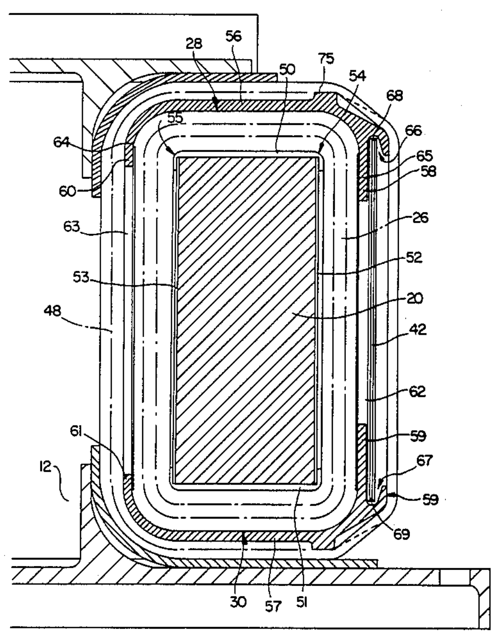
*Primary Examiner*—Thomas J. Kozma
*Attorney, Agent, or Firm*—Ratner & Prestia



[57] **ABSTRACT**

The invention provides a toroidal transformer with integrated self inductance device, comprising a closed main annular magnetic circuit on which an inner electric winding is coiled. A magnetic core, in the form of an open annular sector, is held in position at the periphery of the inner winding by peripheral bars. The assembly is covered by the outer electric winding. The magnetic core determines the value of the self inductance of the transformer.


**13 Claims, 8 Drawing Sheets**



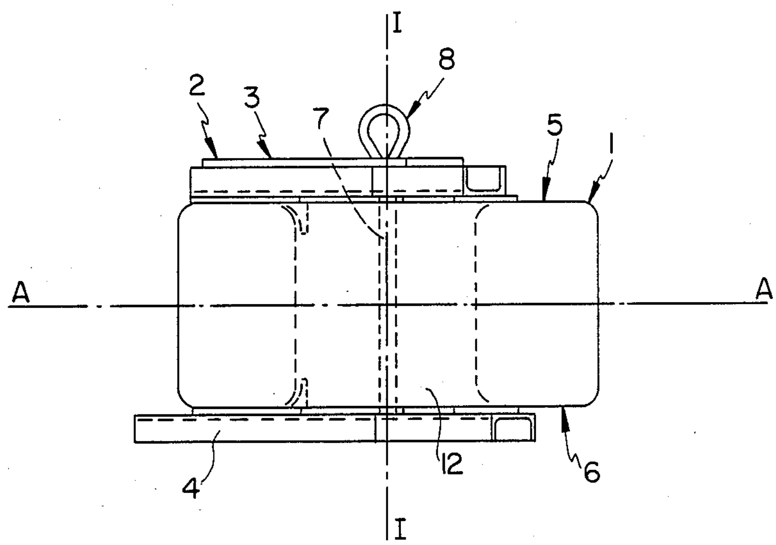



FIG. 1

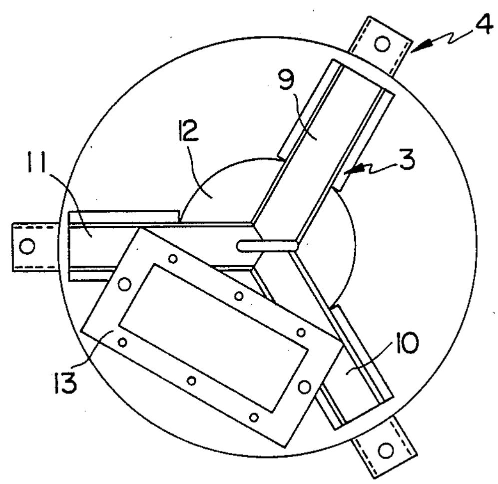



FIG. 2

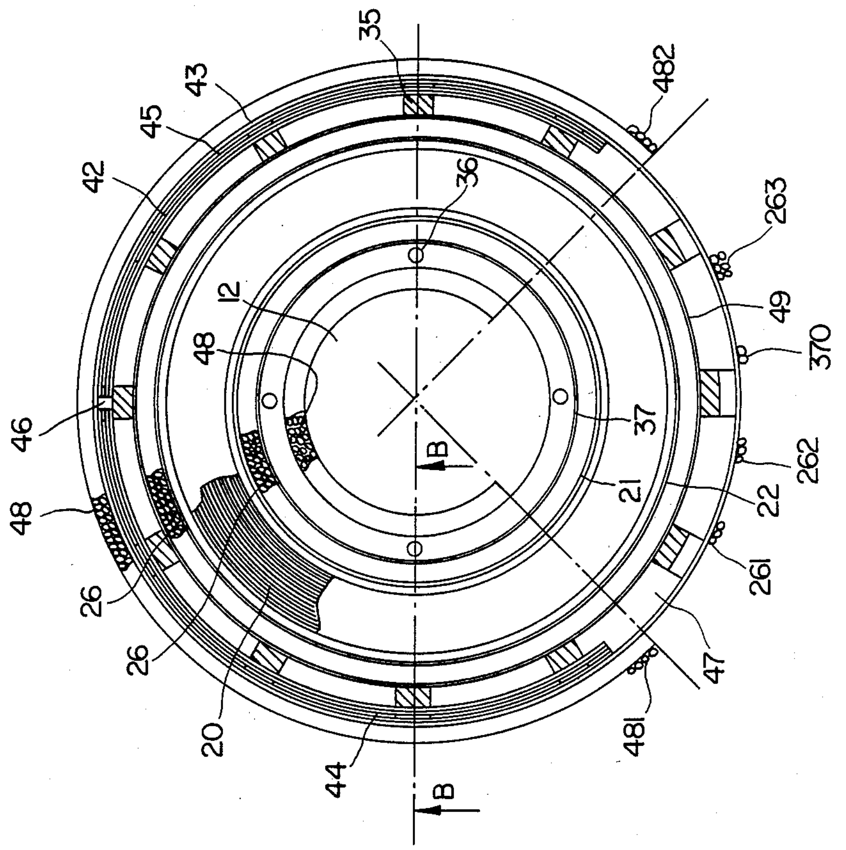

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FIG. 3

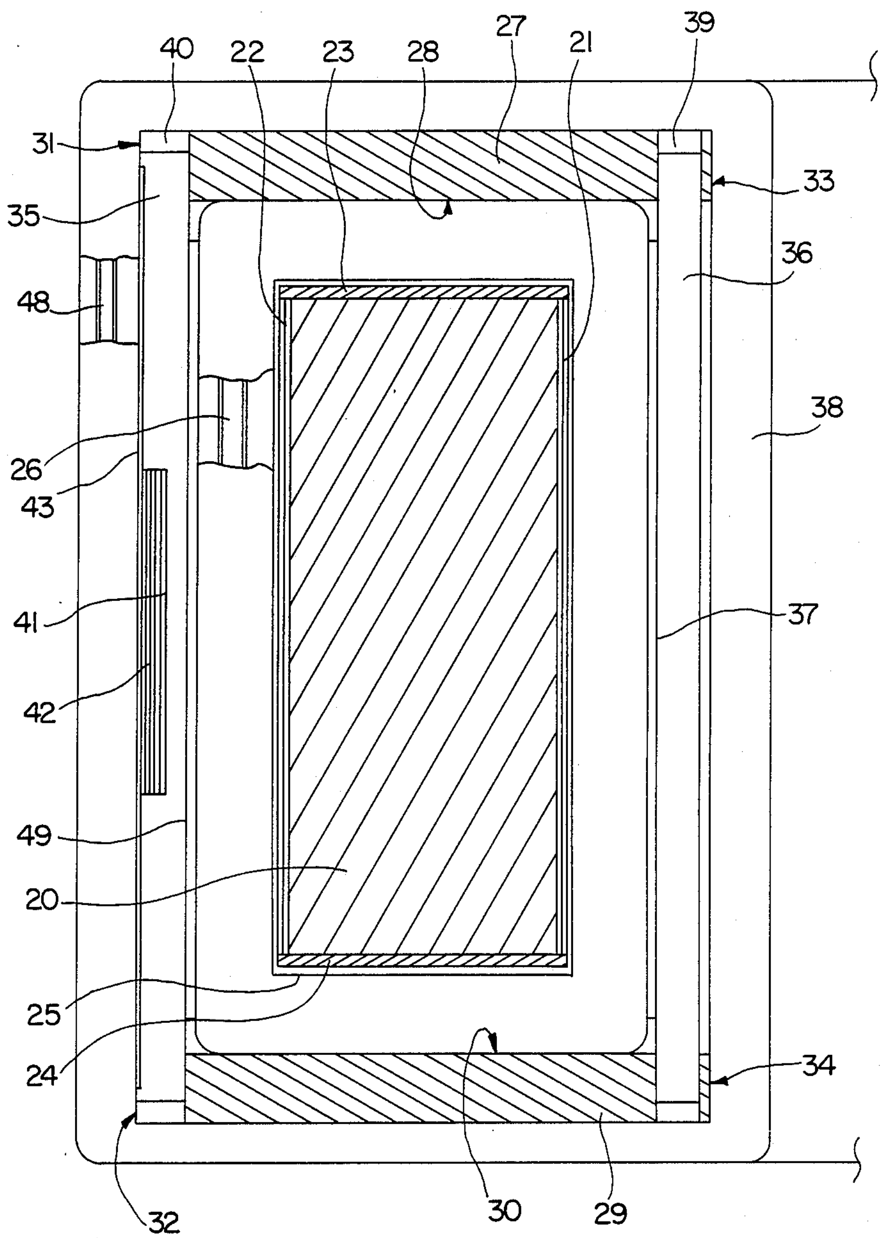
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FIG. 4

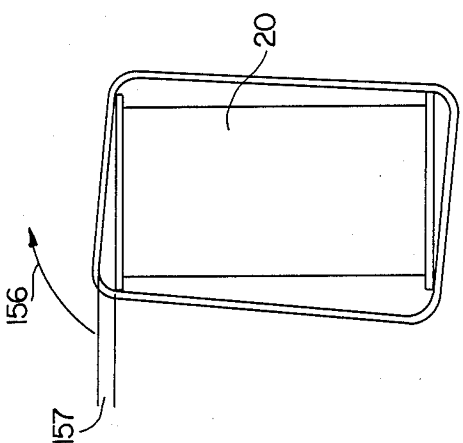


FIG. 5

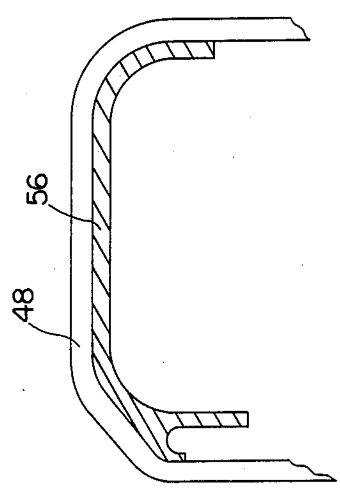


FIG. 6

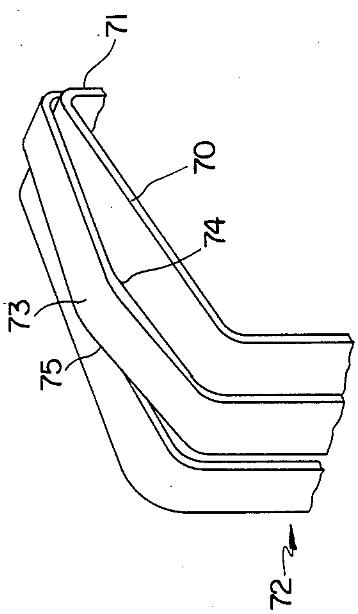


FIG. 7

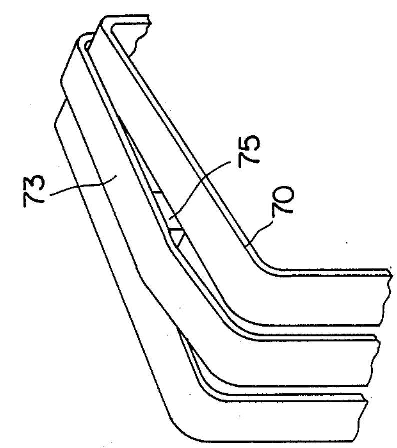


FIG. 8

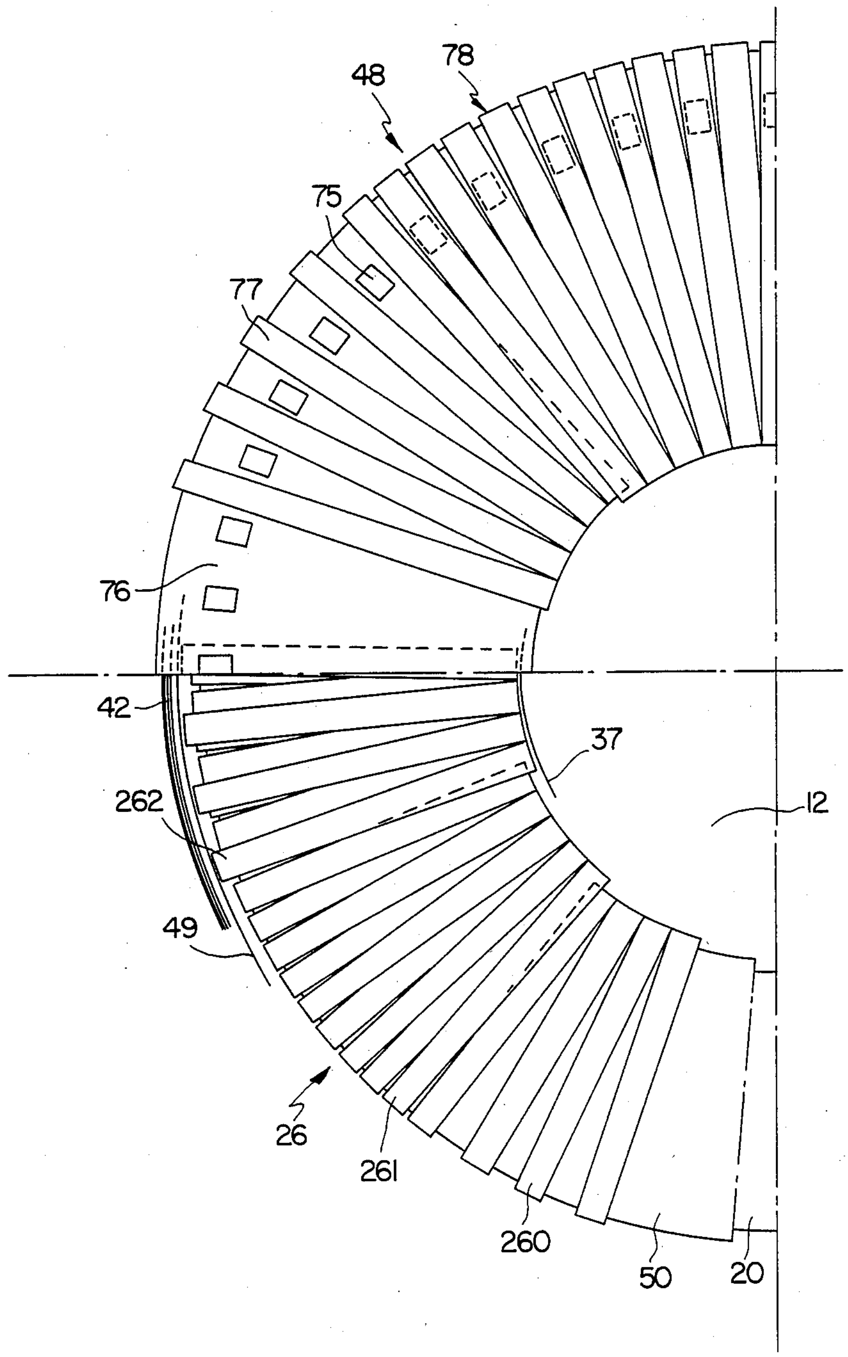


FIG. 9

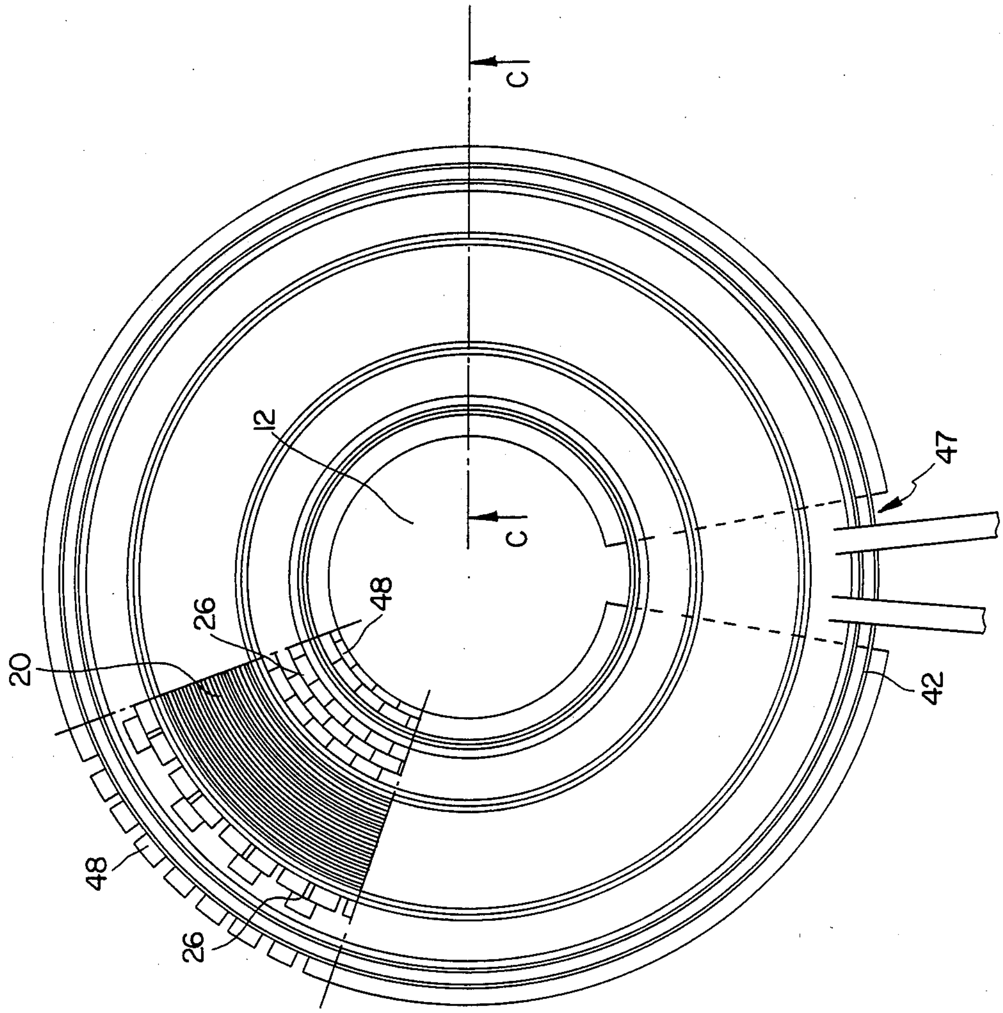


FIG. 10

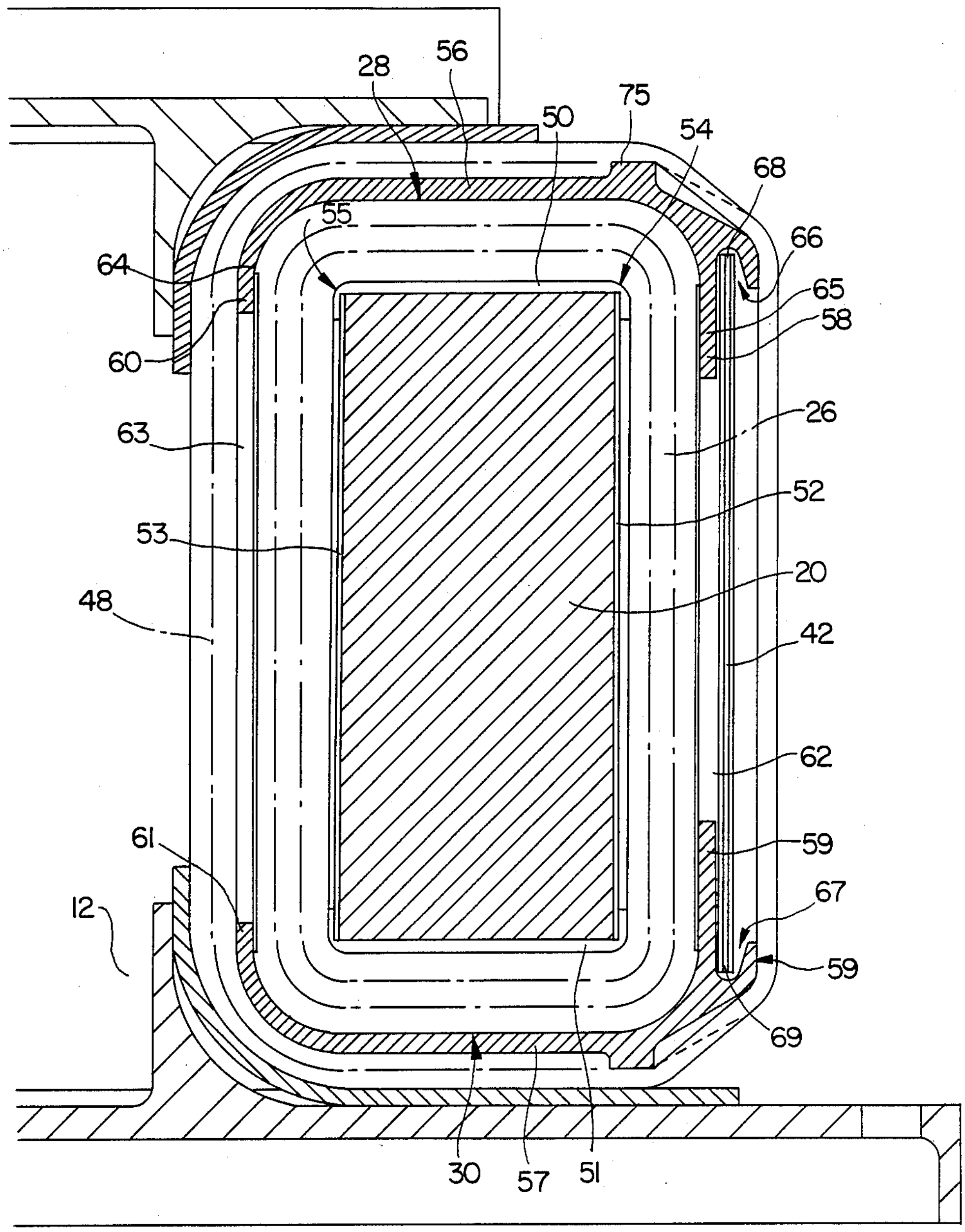
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FIG. 11

# TOROIDAL TRANSFORMER WITH INTEGRATED SELF-INDUCTANCE DEVICE

## BACKGROUND OF THE INVENTION

The present invention relates to electric transformers for transmitting electric power and more particularly to transformers one at least of the windings of which has integrated self-inductance.

Integrated self-inductance transformers are generally formed around a conventional magnetic circuit with two or three parallel columns connected together by two end crosspieces, the primary and secondary windings being coiled about the central column. The integrated self-inductance is obtained by providing an open auxiliary magnetic circuit surrounded by only one of the primary and secondary windings. The secondary magnetic circuit, unsaturable under normal conditions of use, limits for example the short circuit current of the transformer.

Such transformers with conventional magnetic circuit have in particular the drawback of being relatively bulky and heavy : the configuration of the magnetic circuit causes electromagnetic radiation harmful to the neighborhood of the transformer, which radiation is further increased very appreciably when a secondary magnetic core is incorporated for obtaining the self-inductance.

Electric transformers are further known, generally called toroidal transformers, whose magnetic core has a closed annular form. The primary and secondary windings of such a transformer are generally coiled one on the other. It is known that such a transformer is, for equal power, less bulky and less heavy than a conventional magnetic-circuit transformer with two or three columns.

Such a toroidal transformer is however more difficult to construct, and in particular more difficult to wind, since the magnetic circuit is already closed during winding and the electric winding wire must pass as many times through the central chimney of the magnetic circuit as there are turns to form the coil.

Attempts have been made to construct toroidal transformers with integrated self-inductance, by separating the primary and secondary windings from each other, i.e. by coiling a first winding on a first circular sector of the magnetic circuit and coiling the other winding on a second circular sector of the magnetic circuit, different from the first sector.

Such a solution has not proved usable on an industrial scale, for it makes the electric windings even more difficult to coil on the torus and the coiling cannot be readily automated. Such an arrangement further leads to increasing the volumes, the copper sections forming the windings and the heating of the transformer; the self-inductance thus obtained is difficult to control quantitatively when it is desired to design a transformer having new characteristics. It has been further discovered that such a structure leads to increasing substantially the electromagnetic radiation in the vicinity of the transformer.

## SUMMARY OF THE INVENTION

The purpose of the present invention is in particular to avoid the drawbacks of known transformers, by providing a new toroidal transformer structure with integrated selfinductance which is particularly simple and easy to coil and to assemble.

According to another object of the invention, this new structure makes it possible to design a transformer with integrated self-inductance around which the electromagnetic radiation is relatively much smaller.

According to another object of the invention, the structure makes it possible to adjust and control at will the value of the integrated self-inductance, by a simple mechanical displacement of some structural parts; it is thus much easier to design and construct transformers having new electric characteristics and the characteristics may be obtained in a precise way.

According to another object of the invention, the new structure is relatively inexpensive, for the magnetic circuit is formed of elements whose shapes are simple and easy to obtain, and which can be assembled relatively speedily and only requires a small labor force. The structure is further particularly well adapted to providing very complete automation of the assembly.

Another important problem which the present invention solves is the thermal heating appearing in toroidal circuit transformers. For equal power, such heating is relatively greater than in conventional three column magnetic circuit transformers, for in these conventional transformers, the heat exchange surfaces are appreciably greater. In the case of a toroidal transformer, the inner electric winding is completely imprisoned by the electric insulating layers and by the outer electric winding, so that the heat exchanges are considerably reduced.

For that the present invention provides particularly advantageous embodiments, in which the electric insulating means have a shape and structure allowing heat transfer from the inner electric winding to the outer and appreciably increasing the natural cooling of the windings. Consequently, such a structure makes it possible to reduce the section of the conductors, whence a substantial saving in the weight of the copper, a very expensive commodity.

Another object of the invention is to reduce the average length of the turns forming the electric windings of the transformer, without adversely affecting the electric insulation or the cross section of the magnetic circuit.

The invention also makes it possible to coil toroidal transformer with a flat wire of large cross-section. Because of the toroidal shape with rectangular cross-section of the magnetic circuit, the turns are disposed radially. They are therefore jointing in the chimney of the torus and are spaced apart on the external periphery, because of the difference of the developed lengths of the external and internal diameters of the torus. After coiling a first layer of jointing turns in the chimney of the torus, the next layer tends to be superimposed on the preceding one in the bore, but to be inserted between the turns of the first layer on the external periphery. In an intermediate zone, the external turns bear on the internal turns at a point of their edge, so that with the contact taking place over a very small area, it forms a very high pressure bearing zone likely to damage the electric insulation. The invention provides means for avoiding this concentration of tractive forces on two pin-point bearing points on each turn.

Another object of the present invention is to provide correct maintenance of the auxiliary magnetic circuit forming the integrated self-inductance, so as to avoid the vibrations of plates generating harmful noise.

Another important object of the invention, is to considerably reduce the number of parts required for electrically insulating the windings. The result is a reduction in the cost of the raw materials and especially a reduction of the cost of the labor required for assembly.

To attain these objects as well as others, the toroidal transformer of the present invention comprises a main annular closed magnetic circuit, means for electrically insulating the outer surface of the magnetic circuit, an inner electric winding coiled on the insulation of the main magnetic circuit, an intermediate electric insulation surrounding the inner electric winding, and an outer electric winding coiled about the intermediate electric insulation. The transformer of the invention further comprises at least one magnetic core having at least one open annular sector defined by an air-gap and disposed parallel to the main annular magnetic circuit between the inner electric winding and the outer electric winding. The magnetic core defines, by its structure and its position, the value of the self-inductance of the outer electric winding.

In another advantageous embodiment, the magnetic core has at least one annular sector disposed along the periphery of the inner winding. Alternately or complementarily, the magnetic core has a least one annular sector disposed in the central bore of the inner winding.

In a particular embodiment, the core has two successive annular sectors disposed along the periphery of the inner winding. That facilitates insertion of the magnetic core and the adjustment of the inductance by positioning the successive annular sectors.

In a first embodiment, the electric insulating means comprise an upper ring and a lower ring, made from an insulating and rigid material whose external contours are connected together by axial bars forming a support for the peripheral magnetic core. The peripheral magnetic core is advantageously formed of a stack of sheets bent on the periphery defined by the axial bars and on which it is held in position by peripheral insulating taping. This structure considerably facilitates assembly of the transformer, namely the assembly of its components, and the adjustment of the self-inductance may be provided by sliding the sheets in the housing defined between the axial bars and the peripheral taping.

The upper and lower rings advantageously have a circular inner contour of a diameter less than the inner diameter of the main annular magnetic circuit; the rings thus form a support on which the outer winding may be coiled. The rings thus separate the two windings, increase the heat exchange surface, participate in the electric insulation and define a rigid support allowing the coiling of the outer winding to be automated.

In a preferred embodiment, adapted to a form of toroidal magnetic circuit with substantially rectangular cross-section, the electric insulating means include an upper electrically insulating toroidal cap and a lower electrically insulating toroidal cap; each toroidal cap is limited by an outer circular contour of a diameter only a little greater than the outer diameter of the ring formed by the inner electric winding and being defined by an inner circular contour of a diameter only a little less than the inner diameter of the ring formed by the inner electric winding; the respective contours of the upper cap and the lower cap facing each other are separated by a space promoting the transfer of heat energy. This embodiment substantially increases the heat energy transfer from the inner winding to the outer and provides a substantial saving in space in the central bore of the circuit.



The outer faces of the cap edges advantageously have a rounded cross-section. This arrangement substantially reduces the length of copper required for forming the electric winding and improves the evenness of coiling.

The external contour of each of the caps may advantageously comprise an annular groove facing the annular groove of the other cap; the magnetic core comprising a stack of bent metal sheets, is held in position by the caps, the edges of the magnetic core being nipped respectively in the upper cap groove and in the lower cap groove. If required the caps themselves hold in position electrostatic screens for the transformer.

## BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages of the present invention will be clear from the following description of particular embodiments, with reference to the accompanying figures in which:

FIG. **1** shows a general side view of a transformer of the present invention;

FIG. **2** shows a top view of the transformer of FIG. **1**;

FIG. **3** is a top view in section through plane A—A of FIG. **1** in a first embodiment;

FIG. **4** is a half side view in section through plane B—B and on a larger scale of FIG. **3**;

FIG. **5** illustrates the drawbacks of coiling a large diameter wire on a circuit with rectangular cross-section;

FIG. **6** illustrates the advantage of coiling a large diameter wire on a circuit whose corners are rounded;

FIG. **7** illustrates the drawbacks of coiling a flat electric conductor with rectangular cross-section on a toroidal magnetic circuit;

FIG. **8** illustrates on a larger scale the overlapping of the turns in accordance with the present invention;

FIG. **9** is an end axial view of the toroidal transformer electric windings using a flat electric conductor with large cross-section;

FIG. **10** is a top view in section through plane A—A of FIG. **1**, in a second embodiment; and

FIG. **11** is a half side view in section through plane C—C and on a larger scale of FIG. **10**.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

The transformer of the present invention as shown in FIGS. **1** and **2** has a general annular external shape. The body **1** of the transformer is a ring with axis I—I and of substantially rectangular cross-section. The body is secured to a fixing and transport assembly **2** comprising a first end element **3** and a second end element **4** applied respectively on the first side **5** and on the second side **6** of body **1**. The end elements **3** and **4** are connected together by a central connecting column **7** on the top of which is fitted a carrying loop **8**.

In the embodiment shown in FIG. **2**, the end elements such as the first element **3** comprise three divergent arms arranged in a star. Thus, the first end element **3** has arms **9**, **10** and **11**. The arms are joined together at the center, in the axis I—I of the transformer, and are fixed to the central connecting column **7**. The central connecting column **7** passes through the central bore **12** of body **1**. A support plate **13**, fast with the first end element **3**, supports the electric connection terminals of the transformer. The divergent arms have their internal faces shaped so as to mate with the shape of the first side **5** or of the second side **6** of body **1**, in the vicinity of the central bore **12** of body **1**, thus providing lateral solidity between body **1** and the fixing and transport assembly **2**.

FIGS. **3** and **4** illustrate the internal construction of transformer body **1** in a first embodiment of the invention. For a clearer understanding of the drawings, the metal sheets of the magnetic circuit have been shown only partially; the same goes for the conductors forming the transformer windings, which conductors are shown in cross-section in FIG. **3** and in longitudinal section in FIG. **4**.

In the embodiment shown in these figures, the transformer comprises a main magnetic circuit **20** in the form of a closed circular ring with rectangular cross-section. The magnetic circuit is formed in a way known per se by a circular metal sheet winding.

The magnetic circuit **20** is insulated electrically over the whole of its surface. The electric insulation may advantageously be provided by an inner band **21** covering the wall of the inner bore of the magnetic circuit, an outer band **22** covering the peripheral wall of the magnetic circuit, an upper flange **23** covering the upper side of the magnetic circuit and a lower band **24** covering the lower side of the magnetic circuit. The insulation may be completed by taping **25**. The taping holding in position simultaneously flanges **23** and **24** and bands **21** and **22** on the magnetic circuit, so as to define a sub-assembly which can be handled and capable of receiving a winding provided by automatic mechanical means.

The sub-assembly thus formed receives, by coiling in a known way, a first electric winding called inner winding **26**, formed of a suitable number of turns of electric wire coiled about the magnetic circuit **20**.

A flat upper ring **27** is applied against the upper side **28** of the inner electric winding **26** and a flat lower ring **29** is applied against the lower side **30** of the inner electric winding **26**. Rings **27** and **29** are made from an electrically insulating material having sufficient rigidity for supporting and holding the outer electric winding in position without excessive deformation. Preferably, the upper **27** and lower **29** rings have identical external contours **31** and **32**, and internal contours **33** and **34** which are also identical, the rings being both centered on the axis I—I of the transformer. The upper **27** and lower **29** rings are connected together, in the vicinity of their external contours **31** and **32**, by axial bars **35** and, in the vicinity of their internal contours **33** and **34**, by axial columns **36**. In the embodiment shown, the transformer comprises four axial columns such as column **36**, spaced apart evenly along the periphery of the central chimney of the inner electric winding **26**. In one embodiment, columns **36** may bear against the inner wall of the inner electric winding **26**: in another embodiment, an electrostatic screen **37** may be inserted between column **36** and the inner wall of the inner electric winding **26**, as shown in FIG. **4**. The internal contours **33** and **34** have a circular shape of a diameter less than the inner diameter of the ring formed by the inner electric winding **26**, so as to define two surfaces against which the conductors forming the outer electric winding **38** come to bear and are curved.

Similarly, the external contours **31** and **32** form a bearing surface which is circular and wider than the inner electric winding **26**. The rings form a support on which the outer electric winding **38** is coiled and participate in the electric insulation of the windings with respect to each other.

The upper **27** and lower **29** rings are made from an electrically insulating and mechanically rigid material. Columns **36** have a circular cross-section, and their ends are inserted in axial holes **39** of corresponding cross-section in the rings. The bars **35** have a rectangular cross-section and their ends are engaged in radial notches **40** of corresponding cross-section in the rings. The bars have an outer notch **41**, of a length substantially equal to half the height of the magnetic circuit **20**, and of a depth sufficient for receiving the magnetic core **42**. In the embodiment shown, the transformer comprises twelve axial bars such as bar **35**, spaced apart evenly at the periphery of the ring formed by the inner electric winding **26**. In one embodiment, the bars may bear against the inner electric winding. In the embodiment shown, an electrostatic screen **49** is inserted between bars **35** and the inner electric winding **26**.

The magnetic core **42** is formed of a stack of magnetic metal sheets, of rectangular shape, bent and applied radially from the outside in the notches **41** of bars **35**. For that, notches **41** have a length slightly greater than the height of the magnetic core. After application, the metal sheets of the magnetic core **42** are held in position in the notches by a peripheral tape **43** insulating and holding the magnetic core **42** in position.

In the invention, the magnetic core **42** has an open profile in the form of an annular sector, substantially parallel to the main magnetic circuit **20** and defined by an air-gap. In the embodiment shown in FIG. **3**, the magnetic core **42** is formed of a successive first annular sector **44** and a second annular sector **45** disposed along the periphery of the inner electric winding **26**. The ends of the two periphery of annular sectors **44** and **45** are separated on one side by a first air-gap **46** of small thickness and are separated on the other side by a second much larger air-gap **47**. Air-gap **47**, shown in FIG. **3**, occupies a little more than a quarter of the circumference. It will be appreciated that the magnetic metal sheets forming the first sector **44** and/or the second sector **45** may be slid, at the periphery of bars **35**, for adjusting the value of the self-inductance of the transformer.

Bars **35** and columns **36** are secured to the upper **27** and lower **29** rings, for example by bonding or force fitting, so that the assembly forms a one piece sub-assembly able to be coiled by automatic mechanical means for receiving the outer electric winding. Thus, the outer electric winding **48** forms the outer layer of the transformer body. In the embodiment shown, the outer winding **48** covers the magnetic core **42**, the inner winding and a part of the zone of the second air-gap **47**.

In other embodiments, an outer electric winding **48** may be provided which covers the whole of the magnetic circuit and the inner electric winding.

The magnetic core **42**, in the embodiment shown in FIG. **4**, has a height equal to about half the height of the magnetic circuit **20** and is disposed at mid height of the main magnetic circuit **20**. It will be readily appreciated that in accordance with the invention, the magnetic core **42** is disposed between the inner electric winding **26** and the outer electric winding **48**. This magnetic core **42** determines the value of the self-inductance presented by the outer electric winding **48**. The transformer of the present invention may in particular be used by choosing the inner electric winding as secondary winding and the outer electric winding **48** as primary winding, so that the transformer is then a transformer whose primary has self-inductance.

In FIG. 3, references **481** and **482** designate the outputs of the outer electric winding **48**. This winding is formed of four parallel coiled strands. References **261** and **262** designate the ends of the inner electric winding **26** and reference **263** designates the middle point thereof. This winding is formed of three parallel coiled strands. Reference **370** designates the outputs of conductors for grounding the screens **37** and **49**.

Different arrangements of the magnetic core **42** may be envisaged, without departing from the scope of the present invention. Thus, in a second embodiment, the magnetic core **42** may be formed as an annular sector disposed in the central chimney of the inner electric winding **26**.

In a third embodiment, the magnetic core **42** may be formed as an annular sector disposed on one of the sides **28** or **29** of the inner electric winding **26**.

The magnetic core **42** may also be formed of several parts, some parts being disposed on sides **28** and **30**, some other elements being disposed on the periphery or inside the chimney.

FIGS. **8** to **11** illustrate the internal construction of the transformer body **1** in a second embodiment of the present invention.

The main magnetic circuit **20** of this embodiment is the same as that of the embodiment shown in FIGS. **3** and **4**, namely a closed circular ring with rectangular cross-section formed of a circular metal sheet winding. The magnetic circuit **20** is electrically insulated over the whole of its surface. In this embodiment, the electric insulating means for the magnetic circuit comprise an upper magnetic circuit insulating toroidal cap **50**, a lower magnetic circuit insulating cap **51**, each covering respectively the upper face and the lower face of the magnetic circuit **20** and a part of the external and internal side faces of the magnetic circuit, caps **50** and **51** being connected together by an external cylindrical electric insulation **52** and an internal cylindrical electric insulation **53**. The upper **50** and the lower **51** magnetic circuit insulating caps have, on their external faces, an external rounded edge **54** and an internal rounded edge **55**.

The advantage of the rounded edges **54** and **55** is explained with reference to FIGS. **5** and **6**; when the electric conductor is coiled on the toroidal magnetic circuit, and more particularly when the electric insulating conductor has a relatively large cross-section, it is not possible to bend the conductor at right angles when passing over each edge. Thus, in FIG. **5**, when the magnetic circuit has sharp edges, the electric insulating conductor, wound about the magnetic circuit **20** in the direction of arrow **156**, forms rounded corners, each curve beginning on passing over the corner of the magnetic circuit, and ending spaced away from the magnetic circuit, thus defining at each corner a clearance such as clearance **157**. With a conductor whose thickness is about 2 mm such a clearance may exceed 3 mm. The result is that the electric winding occupies an appreciably larger cross-section than the cross-section of the magnetic circuit and this cross-section is offset with respect to the cross-section of the magnetic circuit, as shown in FIG. **5**. Other than the loss occasioned by the increase in volume which results, difficulties in coiling follow and the coiling generally lacks regularity.

On the other hand, by providing rounded edges such as edges **54** and **55**, the electric insulating conductor takes on perfectly the shape of the edge at each passage and is thus correctly applied on the insulator, each of its branches being parallel to the corresponding face of the magnetic circuit. It might be thought that the fact of providing rounded edges **54** and **55** would tend to increase the apparent section of the assembly formed by the magnetic circuit and its external insulator. In actual fact, and surprisingly, it has been discovered that this arrangement tends on the contrary to reduce the length of the conductor turn surrounding the magnetic circuit, resulting in a saving of copper forming the conductor.

Partial taping may fix the insulators **50**, **51**, **52** and **53** around the magnetic circuit. The sub-assembly thus formed then receives, by coiling in a way known per se, the first inner electric winding **26**. In the embodiment shown, the inner electric winding **26** is formed of a suitable number of turns of flat electric insulating conductor with rectangular crosssection. A three layer winding has been shown, a first layer **260** formed of radial turns which are jointing in the central chimney **12** of the circuit and which are spaced apart from each other on the lateral external peripheral face of the circuit; this first layer **260** is covered by a second layer **261**, shown partially in FIG. **9**, formed of radial turns which are also jointing in the central chimney **12**, itself having thereover a third layer **262** of the same structure, which covers it.

An upper toroidal cap **56** is fitted against the upper side **28** of the inner electric winding **26** and a lower toroidal cap **57** is fitted against the lower side **30** of the inner electric winding **26**. The upper **56** and lower **57** toroidal caps are made from an electrically insulating material having a certain flexibility. Preferably, the upper **56** and lower **57** caps are identical. They have respectively circular external contours **58** and **59** of a diameter only a little greater than the external diameter of the ring formed by the inner electric winding **26**. Caps **56** and **57** are defined by a circular internal contour, respectively **60** and **61**, of a diameter only a little less than the inner diameter of the ring formed by the inner electric winding **26**. The external contours **58** and **59** of the two caps **56** and **57** are separated from each other by a space **62** promoting the transfer of heat energy from the inner winding **26** to the outer. Similarly, contours **60** and **61** are separated from each other by a space **63** promoting the passage of heat energy from the inner winding **26** to the central chimney **12**.

The upper **56** and lower **57** caps are formed so as to be applied with a small clearance on the inner winding **26**. After positioning thereof, they may be held in position by any means, for example by a few turns of tape distributed in two or three zones of the periphery of the circuit.

Each cap **56**, **57** has an inner flange **64** partially covering the inner cylindrical face of the inner electric winding **26** and an external flange **65** partially covering the external lateral cylindrical face of the inner electric winding **26**. These flanges ensure fitting of caps **56** and **57** on the inner winding and their thicknes defines the thickness of the air-gap separating the inner electric winding **26** from the outer electric winding or magnetic shunt.

Referring to FIG. **11** it can be seen that the external contours **58** and **59** of the two caps **56** and **57** have a particular shape; thus, the external contour **58** of cap **56** comprises an annular groove **66** and the external contour **59** of cap **57** has an annular groove **67**, grooves **66** and **67** facing each other as shown in the figure.

The magnetic core **42**, formed of a stack of magnetic metal sheets, of rectangular shape and bent, has an upper edge **68** engaged in groove **66** and a lower edge **69** engaged in groove **67**. During coiling of the outer electric winding on top of caps **56** and **57**, the walls of grooves **66** and **67** tend to draw together and nip the edges of the magnetic core **42**. The result is that the metal sheets are held tightly in position, avoiding noise and vibrations, and facilitating their assembly. Despite the clamping, it still remains possible to slide one of the sheets forming the magnetic core **42** for subsequent adjustment of the transformer. In this embodiment, the magnetic core **42** has an open profile, in the form of an annular sector with a single air-gap **47**.

The outer electric winding **48**, formed of radial turns, covers the assembly thus formed. Caps **56** and **57** form the support for the outer electric winding **48**.

The external faces of contours **58, 59, 60** and **61** of caps **56** and **57** advantageously have a rounded cross-section, as shown in FIG. **11**. Because of this rounded section, the average turn of the outer winding **48** has a reduced length, and the coiling is more regular. The external face of caps **56** and **57** further has a feature for solving the problems related to the coiling of a flat electric conductor of large cross-section on a toroidal core. The problem which is met with is illustrated in FIGS. **7** and **8**. Because the turns of a first layer **70** are jointing in zone **71** opposite the central chimney **12** of the circuit, the same turns are spaced apart in the external zone **72**. When an upper layer of turns is wound above the lower layer **70**, for example when conductor **73** is positioned, this conductr overlaps two conductors of the lower layer **70** in the vicinity of zone **71** but tends to insert itself between two conductors of the lower layer **70** in the vicinity of the external zone **72**. Changeover from overlapping to insertio takes place in an intermediate zone, in which conductor **73** is bent and bears at two lateral points **74** and **75** on each of the conductors of the lower layer **70**. These pinpoint lateral bearing points are the seat of a considerable pressure, damaging the conductor insulators.

To avoid this drawback, caps **56** and **57** comprise, on their flat external faces, wedges **75**, distributed evenly in a circle in an intermediate zone between the internal contour and external contour of the caps. Wedges **75** have a height substantially equal to the thickness of the flat conductor, and are separated from each other by a space **76** of a width greater than the width of the flat conductor forming the winding. Thus, to form the outer winding **48**, a first winding layer **77** is formed by conductor turns each engaged between two succesive wedges. A second winding layer **78** is formed by conductor turns each passing over the upper face of a wedge, as shown in FIG. **9**. Thus, as can be seen in FIG. **8**, wedge **75** avoids the lateral pinpoint contact between the conductors of the lower layer **70** and conductor **73** of the upper layer.

Caps **56** and **57** hold the magnetic core **42** mechanically in position. As can be seen from FIG. **9**, caps **56** and **57** may also hold in position electrostatic screens **37** and **49** disposed between the primary winding and the secondary winding of the transformer.

The annular grooves **66** and **67** holding the magnetic core **42** in position may be interrupted over a part of their periphery, making it possible to handle the metal sheets of the magnetic core **42** for moving them by peripheral sliding. The sheets are accessible in the zone of air-gap **47**, which zone is not entirely covered by the outer electric circuit **48**. In actual fact, the outer electric circuit **48** covers the whole of the torus, except for a part of the air-gap **47**.

Advantage may be taken of the presence of caps **56** and **57** for providing, in their upper or lower surface, chimneys for the passage of conductors for holding in position the end of the inner windings and letting them pass.

In the embodiment shown in FIGS. **9** to **11**, only caps **56** and **57** are provided with wedges **75**. Surprisingly, it has been discovered that the presence of these wedges **75** considerably improves the evenness of the turns of the outer winding **48**. The result is substantial improvement in the reproducibility of the electric characteristics of the transformer thus obtained, so that it becomes practically pointless to adjust these electric characteristics, after assembly, by adjusting the metal sheet of the magnetic core **42**.

Caps may further be used comprising wedges **75** disposed no longer between the primary winding and the secondary winding of the transformer but between successive winding layers, thus obtaining the same advantages. Wedges **75** could also be used on caps **50** and **51** of the magnetic circuit. Wedges **75** may also be advantageously used with round crosssection electric insulating conductors.

Caps **56** and **57** between electric insulating windings may advantageously be formed with apertures spaced apart over their surfaces. Such apertures not shown in the figures, promote the heat exchanges from the inner winding to the outer.

The present invention is not limited to the embodiments which have been explicitly described but it includes the different variants and generalizations thereof contained within the scope of the following claims.

What is claimed is

**1**. A toroidal transformer comprising:

a main annular magnetic circuit;

inner electric insulation means surrounding the main ananular magnetic circuit;

inner electric winding means including a plurality of turns of electric wire coiled around said inner electric insulation means;

an auxiliary magnetic core;

intermediate electric insulation means for electrically insulating said inner electric winding and for providing correct maintenance of said auxiliary magnetic core to avoid unwanted vibrations of said auxiliary magnetic core; said intermediate electric insulation means including: an upper rigid electrically insulating ring; a lower rigid electrically insulating ring; and means for engaging and holding said auxiliary magnetic core; and

outer electric winding means including a plurality of turns of electric wire coiled on said intermediate electric insulation means around said inner electric winding means and said auxiliary magnetic core.

**2**. The transformer set forth in claim **1**, wherein:

the upper and lower rigid electrically insulating rings of the intermediate electric insulation means have respective external contours; and said means for engaging and holding said auxiliary magnetic core includes:

a plurality of axial bars, each having first and second ends coupled to the external contours of said respective upper and lower rings, for positioning said upper and lower rings concentrically above and below said inner electric winding, respectively; and

said auxiliary magnetic core includes a stack of bent metal bars configured to be positioned around a periphery of said intermediate insulation means defined by said plurality of axial bars;

wherein each of said axial bars includes an external notch having a length that is at least sufficient to receive said stack of bent metal bars.

**3.** The transformer set forth in claim **1**, wherein each of the upper and lower rings of said intermediate insulation means have an inner contour and an outer contour, wherein the outer and inner contours of each of said upper and lower rings are respectively greater than the outer diameter and less than the inner diameter of a ring formed by said inner electric winding and wherein said upper and lower rings form a support on which said outer electric winding is coiled.

**4.** The transformer set forth in claim **1**, wherein:

said auxiliary magnetic core includes at least one annular section and has first and second ends which define an air-gap; and

said outer electric winding covers said auxiliary magnetic core and only a part of said air-gap.

**5.** The transformer set forth in claim **1**, wherein:

said outer winding includes first and second winding layers formed by turns of a conductor around said intermediate electric insulating means;

one of the upper and lower electrically insulating rings of said intermediate electric insulating means has a relatively flat face which is delimited by an internal contour and an external contour, said one ring having a plurality of wedges distributed evenly around the face of the one ring in an intermediate zone between the internal and external contours, each of said wedges having a height substantially equal to the thickness of the conductor used for the outer winding, and said wedges being mutually separated by a space of a width greater than the width of the conductor used for the outer winding; and

said first winding layer of said outer winding is formed by turns of said conductor each of which is engaged between two successive wedges and said second winding layer of said outer winding is formed by turns of said conductor each passing over a respectively different one of said plurality of wedges.

**6.** The transformer set forth in claim **1**, wherein:

said inner electric winding forms a ring having an inner diameter and an outer diameter;

said upper and lower electrically insulating rings each have the form of a toroidal cap and are engaged concentrically on respective upper and lower faces of the ring formed by said inner electric winding each of said upper and lower toroidal caps having an inner contour and an outer contour that have diameters which are respectively less than and greater than the respective inner diameter and outer diameter of the ring formed by said inner electric winding, wherein said outer contour includes an annular groove;

wherein said upper torodial cap is separated from said lower torodial cap by a space for promoting the transfer of heat energy; and

said auxiliary magnetic core includes a stack of bent metal sheets having first and second edges which are nipped in the annular groove of said upper torodial cap and the annular grove of said lower torodial cap, respectively.

**7.** The transformer set forth in claim **6** wherein the annular grooves are open over a portion of their periphery, allowing the metal sheets of the auxiliary magnetic core to be adjusted by peripheral sliding.

**8.** The transformer set forth in claim **6** wherein:

said auxiliary magnetic core includes at least one annular section and has first and second ends that define an air-gap; and

the outer electric winding covers the auxiliary magnetic core, the inner electric winding and only a portion of the air-gap.

**9.** The transformer set forth in claim **6**, wherein:

said outer winding includes first and second winding layers formed by turns of a conductor around said intermediate electric insulating means;

said top and bottom torodial caps of said intermediate electric insulating means each include a plurality of wedges distributed evenly around the outer surfaces of said torodial caps in an intermediate zone between the internal and external contours, each of said wedges having a height substantially equal to the thickness of the conductor used for the outer winding, said wedges being mutually separated by a space of a width greater than the width of the conductor used for the outer winding; and

said first winding layer of said outer winding is formed by turns of said conductor each of which is engaged between two successive wedges and said second winding layer of said outer winding is formed by turns of said conductor each passing over a respectively different one of said plurality of wedges.

**10.** The transformer set forth in claim **6** wherein each of said upper and lower torodial caps includes an inner flange partially covering the inner cylindrical lateral face of the ring formed by said inner electric winding.

**11.** The transformer set forth in claim **6** wherein each of said upper and lower torodial caps includes an outer flange partially covering the outer cylindrical lateral face of the ring formed by said inner electric winding.

**12.** The transformer set forth in claim **6** wherein each of said upper and lower torodial caps includes an inner flange and an outer flange partially covering the respective inner and outer cylindrical lateral faces of the ring formed by said inner electric winding.

**13.** The transformer set forth in claim **6** wherein said upper and lower torodial caps each includes means for holding electrostatic screens in position between the inner electric winding and the outer electric winding.

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