Dec. 20, 1966 J. KRONSBEIN 3,293,583

TOROIDAL INDUCTOR

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FIG. 1.

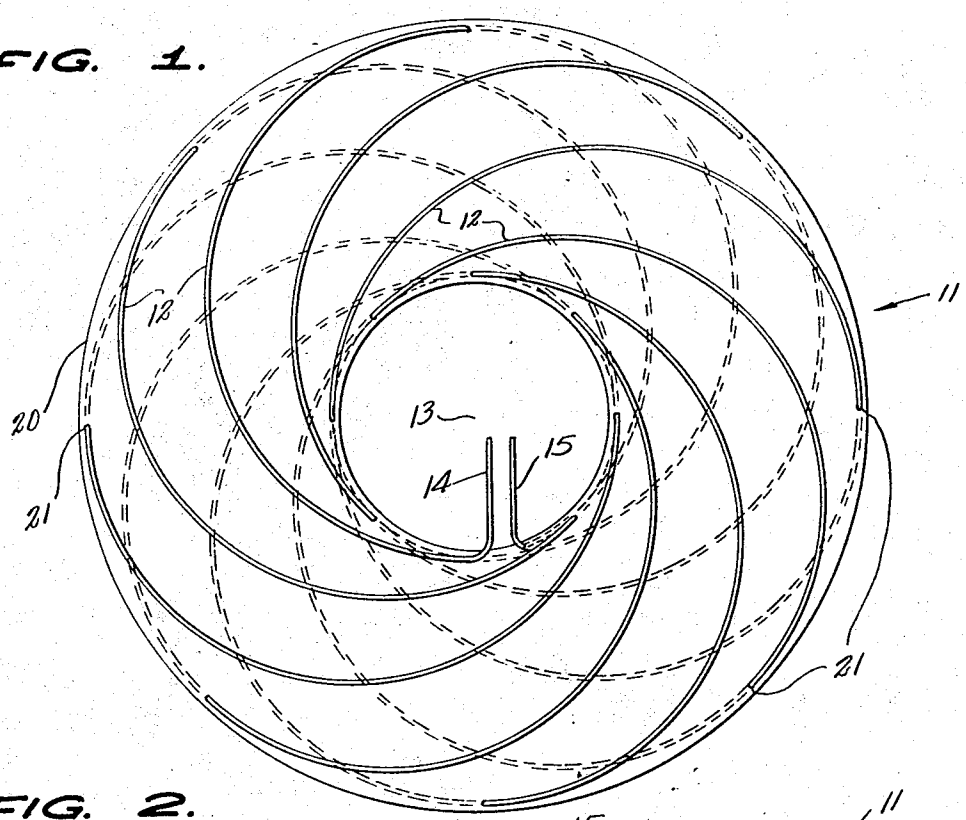


FIG. 2.

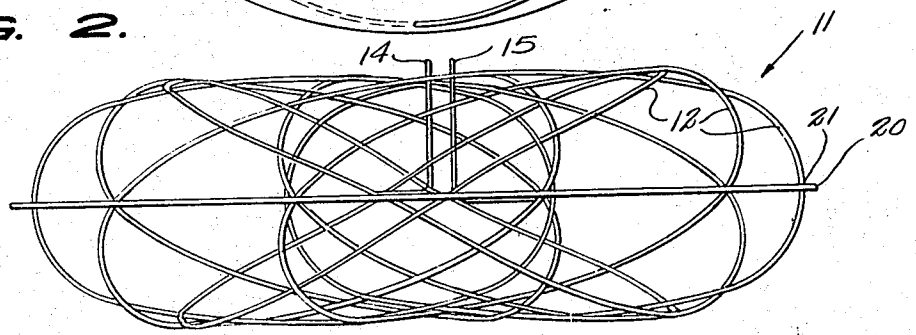
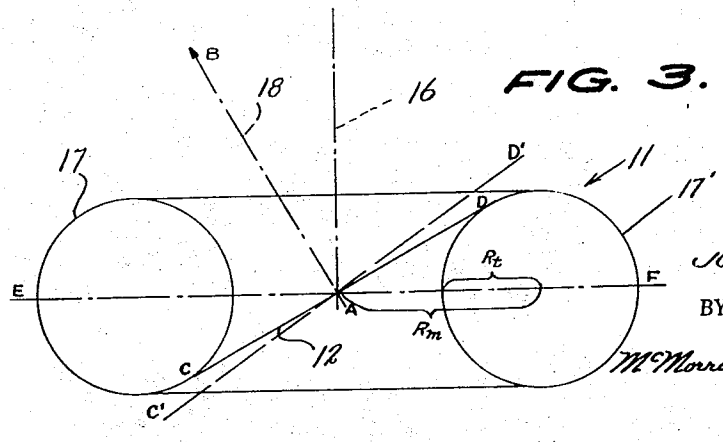


FIG. 3.



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TOROIDAL INDUCTOR

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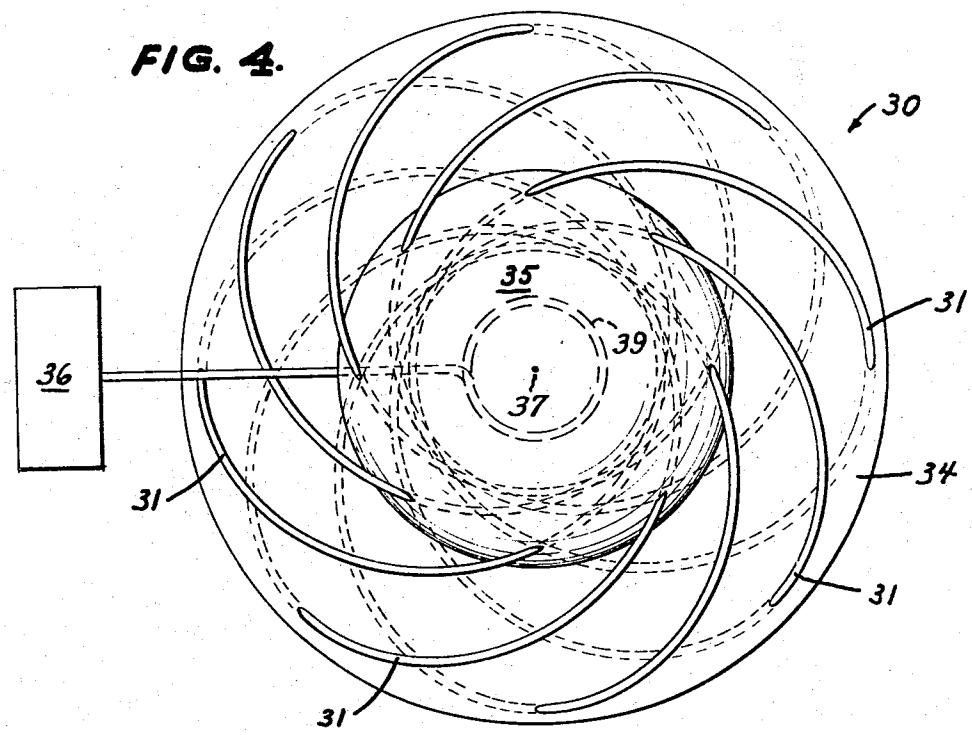
FIG. 4.



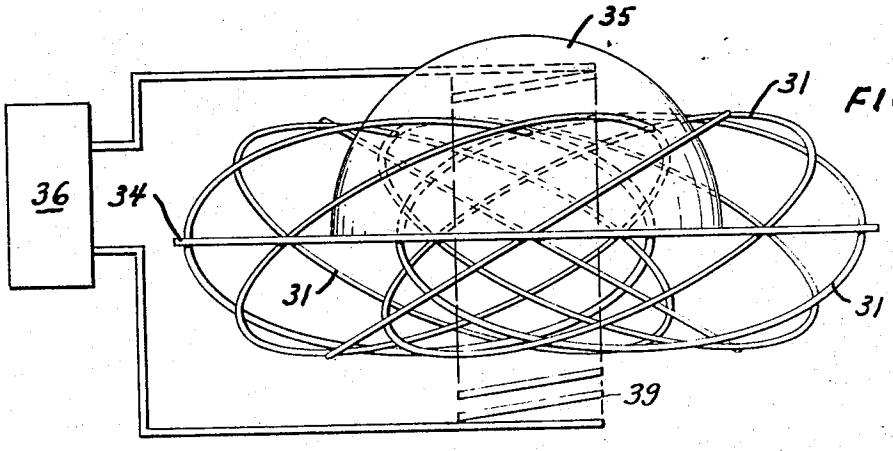


FIG. 5.

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TOROIDAL INDUCTOR

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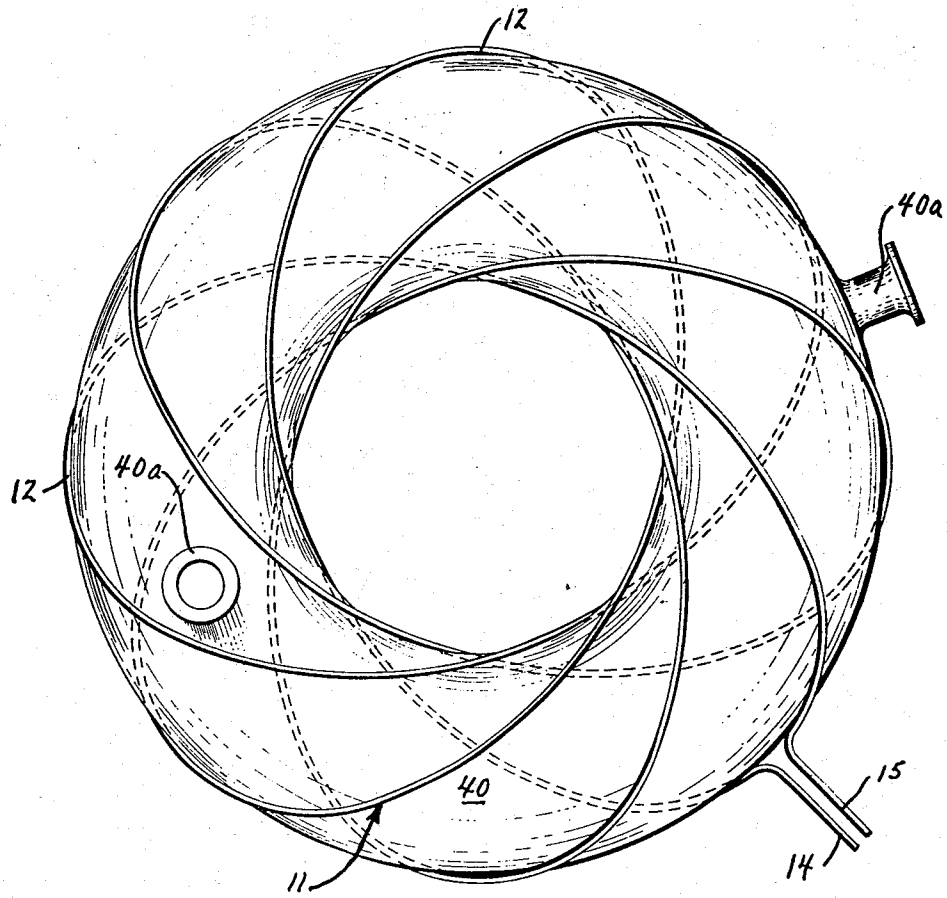

FIG. 6

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TOROIDAL INDUCTOR

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Filed July 17, 1961, Ser. No. 127,082
15 Claims. (Cl. 336—189)

The present invention relates to electrical inductor coils, and more particularly to an improved toroidal inductor, the instant application being a continuation-in-part of patent application Serial No. 795,950, filed February 27, 1959, now abandoned, for Toroidal Inductor.

A main object of the invention is to provide a novel and improved toroidal inductor coil which is relatively simple in construction, which is easy to wind, and which provides a magnetic field which is distributed inside and outside of the toroidal inductor in a manner which substantially prearranges the magnetic field so that the lines of magnetic force are twisted and arranged in a desirable manner, and which is consequently not easily disrupted by the magnetic pressures created when large electric currents are passed through the winding.

A further object of the invention is to provide an improved toroidal coil wound in a manner such as to generate a magnetic field, responsive to flow of current through the coil, said magnetic field being distributed inside and outside of the body of the coil in a manner which may be predetermined by a proper choice of the dimensions of the body to equalize the magnetic pressures inside and outside of the body, whereby distortion of the turns of the coil by the effects of current flow therethrough is substantially avoided and whereby the necessity of providing expensive and complicated means for maintaining the shape of the coil is minimized.

Further objects and advantages of the invention will become apparent from the following description and claims, and from the accompanying drawings, wherein:

FIG. 1 is a top plan view of a toroidal inductor constructed in accordance with the present invention;

FIG. 2 is a side elevational view of the toroidal inductor shown in FIG. 1;

FIG. 3 is a transverse vertical cross sectional view taken through a toroidal inductor constructed in accordance with the present invention and illustrating the manner in which the planes of the circular turns thereof are disposed tangentially to diametrically opposite circular cross sections of the toroid, and diagrammaticaly illustrating how the axis of each turn is inclined with respect to the normal axis of the toroid;

FIG. 4 is a top plan view of a modified toroidal inductor constructed in accordance with the instant invention;

FIG. 5 is a side elevational view of the toroidal inductor shown in FIG. 4; and

FIG. 6 is a side elevational view of a plasma bottle defined in combination with the toroidal inductor of FIGS. 1 and 2.

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiments illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended, such alterations and further modifications in the illustrated device, and such further applications of the principles of the invention as illustrated therein being contemplated as would normally occur to one skilled in the art to which the invention relates.

Toroidal coils, as constructed in accordance with the prior art, have been either wound axially, namely, around the normal axis of the toroid, or transversely to the major

plane of the toroid, namely, in the form of a helical ring comprising a continuous helix of toroidal shape whose turns are each substantially perpendicular to the major plane of the toroid. Thus, in the case of the coil wherein the turns are wound axially, namely around the normal axis of the toroid, the magnetic field produced by the passage of a current through the coil is completely outside the toroidal body and the coil is substantially the same as a solenoid of relatively short length. In a case of the toroidal coil wherein the turns are in planes substantially normal to the major plane of the toroid, the magnetic field developed by the passage of a current through the coil is largely confined within the toroidal body itself. In either case, the magnetic pressures developed are not equalized and due to the unbalance created, the coil is relatively easily distorted or disrupted by the magnetic forces generated when large currents are passed through the winding. This creates the necessity of providing expensive, bulky and heavy reinforcing means for the coil so that the shape thereof will be maintained and so that the forces created by the passage of large currents through the coils will be adequately resisted to prevent undesirable deformations of the turns of the coil.

A prime purpose of the present invention is to provide a toroidal coil which generates a substantially symmetrical magnetic field, and wherein each individual turn of the entire winding links each other turn. The turns are arranged so as to generate a magnetic field which is distributed both inside and outside of the toroidal body defined by the coil in a manner such that, by a proper choice of transverse to meridian radius of the torus, substantial equalization of the magnetic forces acting on the coil from the inside and the outside thereof may be obtained.

Furthermore, the present invention contemplates an arrangement of the turns in a toroidal coil such that a novel type of symmetry of the magnetic field is obtained; namely, wherein the field is not only axially symmetrically arranged but is also symmetrical with respect to the center point of the coil.

The term "transverse radius" signifies the radius of a transverse circular cross section of the toroidal body, whereas the term "meridian radius" signifies the radius of the circle on which the toroidal body is generated.

As will be presently apparent, the toroidal coil of the present invention is neither of the "transverse" type, wherein the individaul turns are substantially in planes perpendicular to the major axis of the toroidal body, nor of the "meridian" type, wherein the turns are wound around the normal axis of the toroid.

Referring to FIGS. 1, 2 and 3, **11** generally designates one form of improved inductor constructed in accordance with the present invention. The inductor **11** comprises a continuous winding of successive circular turns **12** of wire laid over each other and angularly spaced around a common axis, for example, the axis defined by the point **13** of FIG. 1 which is the point of intersection of the common axis and the major plane of the toroid. Thus, the circular turns **12** may be considered as starting with a terminal wire **14** and advancing in a clockwise direction around the point **13** to define a continuous helix in the form of a toroidal body which terminates at a terminal wire **15** disposed adjacent to the lead **14**. As will be readily apparent from FIG. 1, the diameter of each turn **12** is substantially greater than the diameter of a transverse circular cross section of the toroidal body, and each turn **12** lies in a plane which is inclined to the normal axis of the toroid, shown at **16** in FIG. 3. The plane of each turn **12** is tangent to opposite transverse cross sections of the toroidal body, as is clearly apparent from FIG. 3, being tangent, for example, to the lower portion

of the left hand transverse circular cross section 17 and tangent to the upper portion of the right hand transverse circular cross section 17' of the toroid diametrically opposite the transverse cross section 17.

As will be further apparent, since the circular turns 12 are spaced at substantially equal angles around the point 13, assuming that said turns progress in a clockwise direction, as illustrated in FIG. 1, the respective planes of the circular turns 12 are inclined at the same angle to the normal axis 16 of the toroid. Thus, when current passes through the coil, each turn generates a magnetic field whose moment is directed along an axis 18 inclined at a constant angle to the normal axis 16 of the toroid. However, the center of each of the circular turns 12 does not coincide with the normal axis of the toroid but is eccentric with respect thereto, the axis of each turn 12 being skewed with respect to the normal axis 16 of the toroid. This is readily apparent from FIG. 1, wherein it will be seen that the center of each circular turn 12 is offset inwardly relative to the point 13, which defines the location of the normal axis of the toroid.

Since each turn 12 generates a magnetic field responsive to the passage of current through the coil, a substantial portion of the magnetic field is contained inside the toroidal ring as well as outside of said ring. By a proper choice of the ratio between the transverse and the meridian radii of the torus, identified at R*t* and R*m* in FIG. 3, the magnetic pressures inside and outside the torus may be substantially equalized, whereby to minimize the mechanical forces acting on the turns of the coil responsive to the passage of a large current therethrough, thus minimizing deformation or distortion of the coil under operating conditions.

As shown in FIG. 3, the magnetic moment vector, defined by the line AB and designated at 18 in FIG. 3, is perpendicular to the diameter of the turn 12. While FIG. 3 shows the turn 12 as being tangent to the diametrically opposite transverse circular cross sections of the toroidal body shown at 17 and 17', actually, the diameter of the turn is tangent and the coil itself is contained in a plane which is inclined in a manner such that the center of the turn does not coincide with the point A in FIG. 3. However, the magnetic moments may be resolved so that said magnetic moments may be considered as passing through the point A located midway between the tangent points CD in FIG. 3.

The coil 11 may be wound on any suitable toroidal form, or may be merely supported in a circular plate member 20 which is apertured at 21 for the passage of the circular turns therethrough and which may be disposed substantially in the major plane of the toroid. The portions of the turns 12 passing through the disc 20 may be suitably cemented to said disc to provide rigidity and to positively establish the locations of the turns.

As will be readily apparent, each turn 12 of the coil links all the other turns.

It should be understood that the coil may be wound around the toroidal axis advancing in a clockwise direction, as viewed in FIG. 1, or alternatively, may be wound in a direction proceeding counterclockwise around the major normal axis of the toroid. Furthermore, the coil may be wound in a plurality of layers, each layer being wound on top of a previous layer so that the turns of the successive layers are at progressively steeper angles to the major plane of the toroid, namely, to the plane EF shown in FIG. 3. The dotted line C'D' in FIG. 3 illustrates how the diameter of the turn of a second layer is inclined more steeply to the line EF than the diameter CD of a circular turn of the first layer. Due to the fact that the diameters of the circular turns of the successive layers become more and more steeply inclined relative to the major plane of the toroid, the equalizing effect of the distribution of the magnetic fields inside and outside the toroidal body is considerably enhanced. Thus, by employing a plurality of layers similar to the single toroidal layer illustrated in FIGS. 1 and 2, said layers being laid over each other, the equalization of the magnetic forces acting on the coil and the rigidity of the coil are substantially increased.

There is a unique ratio of transverse to meridian radius such that single-layer coils can be wound wherein the right-handed coils would be exactly at right angles to the corresponding left-handed coils if they were wound simultaneously and laid one on top of the other. This type of coil has special properties and is included within the spirit of the present invention.

From the foregoing description, it will be apparent that the toroidal inductor above described provides a distribution of the magnetic fields developed responsive to the passage of current through the respective turns in a manner such that substantial portions of said magnetic fields are distributed inside as well as outside the body of the toroidal body. Therefore, the magnetic forces developed by the passage of current through the coil and acting on the inside and outside of the toroidal body can be substantially counterbalanced, and disruption or distortion of the coil can be minimized. The construction of the coil can therefore be greatly simplified and large currents may be carried by the coil without requiring special structures to maintain the shape of the coil or to otherwise protect the coil against the effects of magnetic forces.

While the inductor described in the foregoing is intended primarily for use with direct current, it is also adaptable for use with alternating currents, since the same considerations will apply and balancing of the magnetic forces inside and outside the body of a toroid will still be achieved, even though the coil is used to carry alternating currents.

With reference now to FIGS. 4 and 5, a modified toroidal inductor 30 is disclosed comprising individual turns 31, each of which is substantially circular in shape. For purposes of rigidity, the individual turns 31 may extend through a base plate 34, typically made from a plastic material, where the assembly further includes a dome 35, also typically made from a plastic material, secured to the aforesaid base plate 34, as through adhesive means, for example. As should be apparent from the drawing, the individual turns 31 not only extend through the base plate 34, but also extend through the aforesaid dome 35.

Where the modified toroidal inductor 30 is employed, each of the individual turns 31 thereof is excited separately, either from a separate source of current supply or from a common source. In this connection, FIGS. 4 and 5 show an alternating current generator 36 driving a coil 39 as a means of energization. The modified toroidal inductor 30 provides optimum operating results, and its geometry is such as to define a torus centered at an axis, represented by reference numeral 37 in FIG. 4, extending at right angles to the base plate 34.

With reference now to FIG. 6, an inductor 11, typically of the type described above in connection with FIGS. 1 and 2, is shown wound around a toroidal container or former 40, which may be made from hollow glass or quartz, for example, and within which a conducting plasma, such as ionized gas, is contained. It should be understood that the inductor 30 of FIGS. 4 and 5 can also be effectively used in this connection.

In any event, in response to the passage of current through its coil windings, the toroidal coil forces the plasma articles to follow a path which gradually dampens out any random collisions between the separate particles, so, and ultimately, they move in unison without creating disorder due to random collisions. The particles move in orbits around the inside of the coil, so that they twist once around themselves while going around the torus once, a unique type of orderly vortex motion of the particles constituting the plasma. Thus, the present inven-

tion may be employed as part of what is known as a "plasma bottle."

In this latter connection, and again with reference to FIG. 6, the container or former **40**, which, it should be apparent, is dough-nut shaped, would have, for example, several tubules **40***a* on the top and sides thereof in order to connect to suitable vacuum making equipment, such as an evacuating plant, and also to provide lead electrodes into the interior thereof. The tubules **40***a* could also serve other uess, such as, for example, measuring, exploring, and the like.

In use, the gas which is to be ionized is introduced through one of the tubules **40***a* in the container or former **40** and, thereafter, is ionized by a suitable electromagnetic field, light beams or the like. The plasma, which is a fully ionized gas, is then held in a suitable ring shaped part of the inside of the container **40** by a field supplied by the windings of the coil on the outside thereof.

Moreover, it should be understood, as noted hereabove, that the magnetic field can be arranged by suitable choice of the ratio of the transverse radius to the meridian radius of the torus shaped coil, which, additionally, solves the so called "containment problem" for plasmas. In other words, such choice of ratio overcomes the Fermi effect which causes charged particles inside a toroidally shaped magnetic field of the ordinary kind to drift towards the walls of the container, and, therefore, to escape the "magnetic bottle." Thus, the ordinary toroidal magnetic field has a field gradient in the direction of increasing radius of the torus (meridian radius), and a field in the direction of the meridian generator circles of the torus (azimuthal direction), whereby mathematics show that the charged particles drift in a direction at right angles to the field and to the field gradient.

By virtue of the instant invention, not only is an azimuthal field component present, but also a "Z-component," the latter being a vertical component at right angles to the meridian plane and, therefore, also the equator plane. When the transverse radius of the torus is chosen sufficiently large in comparison with the overall (meridian) diameter, the drift, in the instant invention, leads the charged particles to move in the neighborhood of other tori inside of the outside field generating torus on which the windings are laid. Thus, the charged particles remain inside the torus without drifting towards the walls.

While specific embodiments of improved toroidal inductors have been disclosed in the foregoing description, it will be understood that various modifications within the spirit of the invention may occur to those skilled in the art. Therefore, it is intended that no limitations be placed on the invention except as defined by the scope of the appended claims.

I claim:

1. An inductor comprising a continuous winding of successive turns of wire forming a continuous helix of toroidal shape, and having a substantially circular cross section in a transverse radial plane, each of said turns being located in a plane which is inclined with respect to the normal axis of the toroidal helix and which is substantially tangent to diametrically opposite circular cross sections of said toroid.

2. An inductor comprising a continuous winding of substantially circular turns of wire laid over each other and angularly spaced around a common axis to define a continuous helix in the form of a toroidal body, and having a substantially circular cross section in a transverse radial plane, each of said turns being located in a plane which is inclined with respect to the normal axis of the toroidal helix and which is substantially tangent to diametrically opposite transverse circular cross sections of said toroidal body.

3. An inductor comprising a continuous winding of substantially circular turns of wire laid over each other and angularly spaced around a common axis to define a continuous helix in the form of a toroidal body, and having a substantially circular cross section in a transverse radial plane, said winding having end terminals located adjacent each other on said toroidal body, each of said turns being located in a plane which is inclined with respect to the normal axis of the toroidal helix and which is substantially tangent to diametrically opposite transverse circular cross sections of said toroidal body.

4. An inductor comprising a continuous winding of successive turns of wire forming a continuous helix of toroidal shape, and having a substantially circular cross section in a transverse radial plane, each of said turns being located in a plane inclined at the same angle to the normal axis of the toroid and being substantially tangent to diametrically opposite upper and lower portions of the circular cross sections of said toroid.

5. An inductor comprising a continuous winding of substantially circular turns of wire laid over each other and angularly spaced around a common axis to define a continuous helix in the form of a toroidal body, and having a substantially circular cross section in a transverse radial plane, the diameter of each turn being substantially greater than the diameter of a transverse circular cross section of the toroidal body and being substantially less than the maximum outside diameter of the toroidal body, each of said turns being located in a plane which is inclined with respect to the normal axis of the toroidal helix and which is substantially tangent to diametrically opposite upper and lower portions of the transverse circular cross sections of said toroidal body.

6. An inductor comprising a continuous winding of successive turns of wire forming a continuous helix of toroidal shape, and having a substantially circular cross section in a transverse radial plane, each of said turns being located in a plane inclined at the same angle to the normal axis of the toroid and being substantially tangent to diametrically opposite upper and lower portions of the circular cross sections of said toroid, the diameter of each turn being substantially greater than the diameter of a transverse circular cross section of the toroidal body and being substantially less than the maximum outside diameters of the toroidal body, said winding having end terminals located adjacent each other on said toroidal body.

7. An inductor comprising a continuous winding of substantially circular turns of wire laid over each other and containing and being angularly spaced around a common axis skewed with respect to the axis of each turn, to define a continuous helix in the form of a toroidal body having a substantially circular cross section in a transverse radial plane and whose normal axis coincides with said common axis, the diameter of each turn being tangent to diametrically opposite top and bottom portions of the transverse cross section of the toroidal body.

8. An inductor comprising a continuous winding of substantially circular turns of wire laid over each other and containing and being angularly spaced around a common axis skewed with respect to the axis of each turn, to define a continuous helix in the form of a toroidal body having a substantially circular cross section in a transverse radial plane and whose normal axis coincides with said common axis, each of said turns being located in a plane substantially tangent to diametrically opposite top and bottom portions of the transverse circular cross sections of said toroidal body.

9. An inductor comprising a continuous winding of substantially circular turns of wire laid over each other and containing and being angularly spaced around a common axis skewed with respect to the axis of each turn, to define a continuous helix in the form of a toroidal body having a substantialy circular cross section in a transverse radial plane and whose normal axis coincides with with said common axis, the diameter of each turn being tangent to diametrically opposite top and bottom portions of the transverse cross section of the toroidal body, and means supportingly engaging each of said turns sub-

stantially at the major central plane of said toroidal body.

10. An inductor comprising a continuous winding of substantially circular turns of wire laid over each other and containing and being angularly spaced around a common axis skewed with respect to the axis of each turn, to define a continuous helix in the form of a toroidal body having a substantially circular cross section in a transverse radial plane and whose normal axis coincides with said common axis, each of said turns being located in a plane substantially tangent to opposite transverse circular cross sections of said toroidal body, the diameter of each turn being tangent to diametrically opposite top and bottom portions of the transverse cross section of the toroidal body, said winding having end terminals located adjacent each other substantially on s aid toroidal body, and means supportingly engaging each of said turns substantially at the major central plane of said toroidal body.

11. A toroidal magnetic coil having a substantially circular cross section in a transverse radial plane and comprising a continuous winding consisting of successive circular turns of wire whose diameters are each substantially equal to a line tangent to diametrically opposite top and bottom portions of the circular transverse cross sections of the coil and each turn being contained in a plane inclined to the major central plane of the coil.

12. A toroidal magnetic coil comprising individual closed turns of wire, where the plane of each closed turn is inclined with respect to each other, and having a substantially circular cross section in a transverse radial plane.

13. A toroidal magnetic coil comprising individual closed turns of wire, where the plane of each turn is inclined to the major central plane of said coil, and having a substantially circular cross section in a transverse radial plane.

14. An article of manufacture comprising a container for a conducting plasma having a coil disposed thereabout, said coil being individual closed turns of wire defining a toroid, where each turn is contained in a plane inclined to the major central plane of said coil, and having a substantially circular cross section in a transverse radial plane.

15. An article of manufacture comprising a container for a conducting plasma having a coil disposed thereabout, said coil being a continuous winding consisting of successive turns of wire defining a toroid, where each of said turns is located in a plane which is inclined with respect to the normal axis of said toroid and which is substantially tangent to diametrically opposite circular cross sections of said toroid.

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