

March 4, 1969

L. J. DONADIEU

3,431,523

SUPERCONDUCTIVE QUADRIPOLE WITH MAGNETIC FOCUSING

Filed April 18, 1967

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FIG. 1

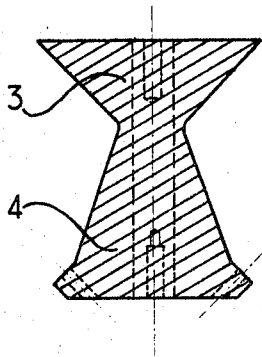


FIG. 3

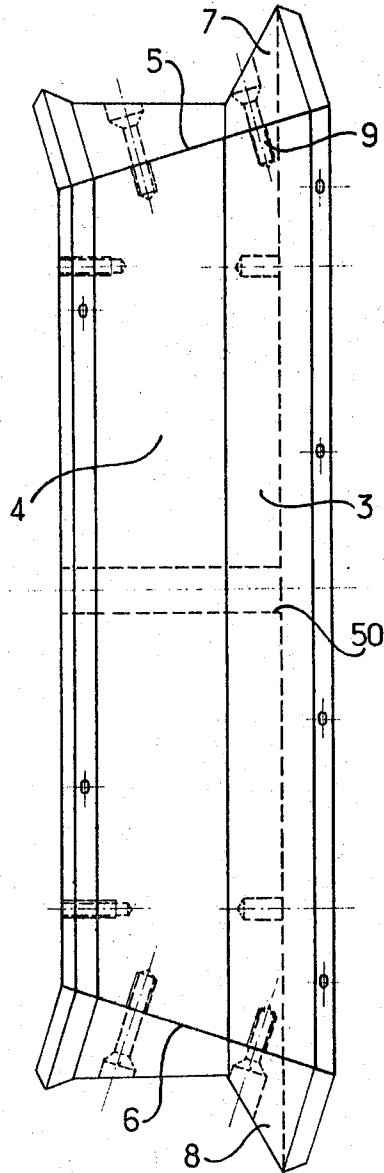
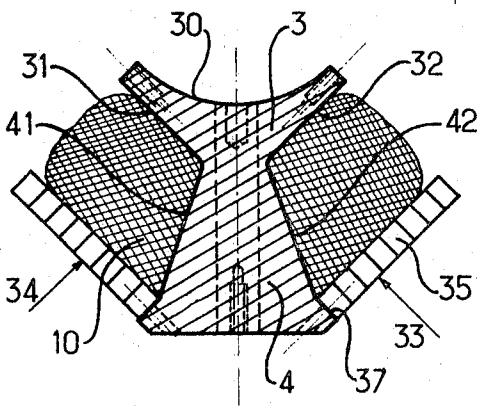


FIG. 2



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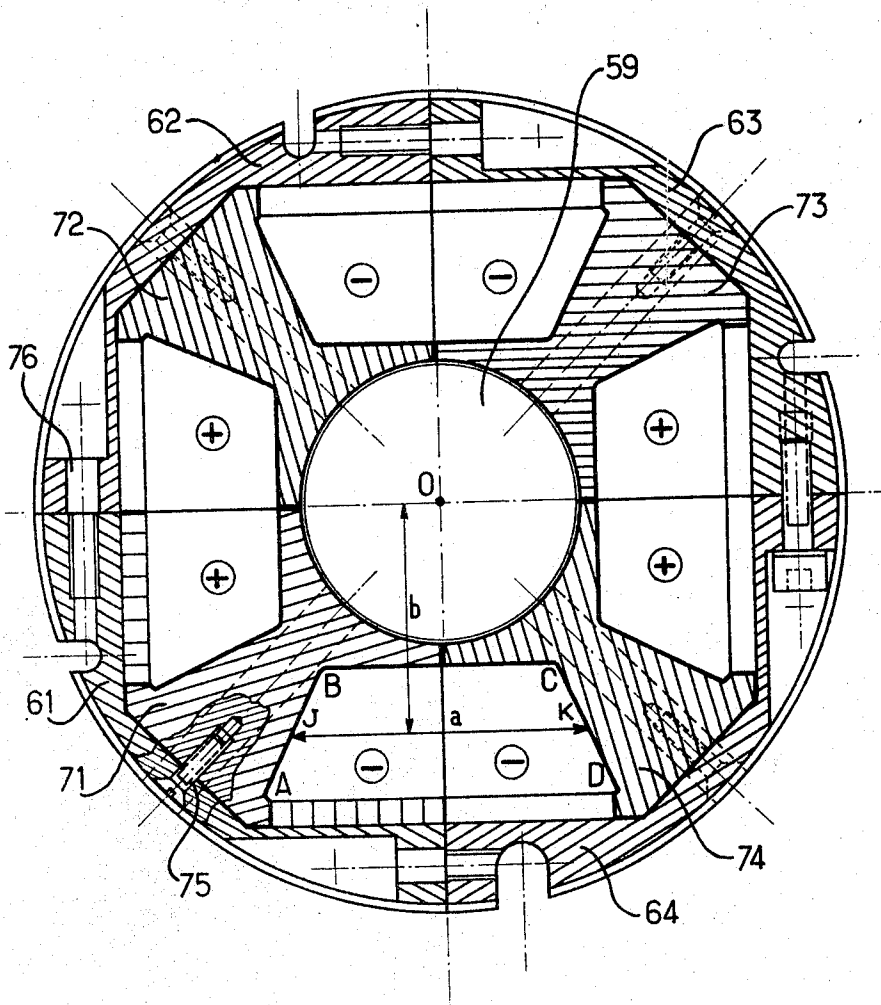
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FIG. 4



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FIG. 5

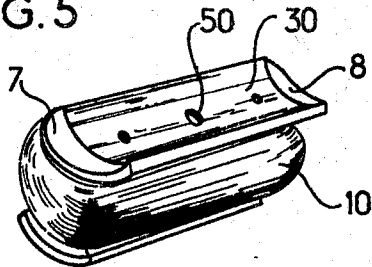


FIG. 6

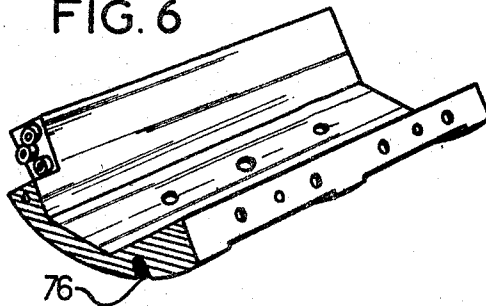
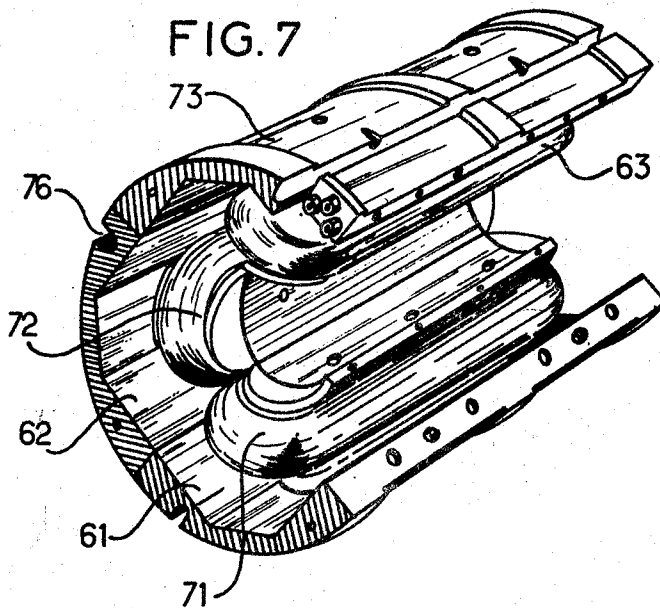


FIG. 7



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**SUPERCONDUCTIVE QUADRIPOLE WITH
MAGNETIC FOCUSING**

Lucien J. Donadieu, Sevres, France, assignor to Com-
pagnie Generale d'Electricite, Paris, France

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58,399

U.S. Cl. 335—210

Int. Cl. H01f 7/22

16 Claims

ABSTRACT OF THE DISCLOSURE

Quadripole with magnetic focusing including four superconducting coils in which each coil has a core having a metallic element of prismatic form, with a section substantially in the form of two isosceles trapeziums having their small base in common, the equal sides of one of the trapeziums including an angle of between 30 and 50°.

The principle of the magnetic, quadripolar iron-free lens is well known (notably from the work of Professor Septier of the Faculty of Science, Paris), in particular from an article entitled "Les lentilles magnetiques quadripolaires sans fer" (magnetic quadripolar iron-free lenses) which appeared in *Le Journal de Physique et le Radium, physique appliquee*, tome 21, supplement au No. 3 Mars 1960 (*The Physics and Radium Journal, Applied Physics, Volume 21, Supplement to No. 3, Mar. 1960*).

There is nevertheless only restricted interest in apparatus based on these principles and provided with conventional coils, for instance, in cooled cooper, because of the low current strengths that can be obtained and also because of the considerable electric power that is necessary for their functioning.

The recent appearance of superconductive materials has made it possible to make magnetic quadripoles having coils which do not have the above-mentioned deficiencies. In actual fact, high current strengths of the order of some hundreds of amps per square millimetre can easily be attained. Moreover, by causing the coils to function below their critical temperature, their resistance becomes null and the power consumed by the unit is then restricted to the thermal losses of the cooling members.

One difficulty in making superconductive quadripoles is to find a mechanical structure which stands up to electromagnetic forces exerted between the coils when current is flowing through them, which may be of the order of tons.

An aim of the present invention is to construct a superconductive quadripole with magnetic focusing which is resistance to internal electromagnetic forces, while obtaining a magnetic field gradient of great homogeneity.

The invention consists in an electric coil for a quadripole with magnetic focusing, comprising a core having a metallic element of prismatic form, the section of which is substantially in the form of two isosceles trapeziums, with their small base in common. They are provided on their end faces with end pieces, and an electric winding is wound on the core parallel to the generatrices of the prism.

In accordance with a feature of the invention, the angle formed by one of the trapeziums of the section of the core has a value between 30 and 50°, preferably 40°.

The invention also consists in a method of winding a coil as set forth above, in which the core of the coil is fixed on the shaft of a winding machine and the winding is retained laterally by side pieces formed by the stacking of small rods, put in place as and when its thickness increases.

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The invention will be further described with reference to the accompanying drawings, which show preferred embodiments of the invention given by way of example only and not by way of limitation.

In the drawings:

FIGURE 1 is a section of the core of a coil of the quadripole in accordance with one embodiment of the invention;

FIGURE 2 is a section of a coil provided with a core in accordance with a variation;

FIGURE 3 is a view in elevation of the core in accordance with FIGURE 2;

FIGURE 4 is a section of the quadripole through a plane perpendicular to its axis;

FIGURE 5 is a perspective view of the core provided with a winding;

FIGURE 6 is a perspective view of an element of the shell of the quadripole; and

FIGURE 7 is a perspective view of the quadripole in a partly assembled form.

The core of the coil is comprised essentially of a prismatic metallic portion terminated by end pieces of plastic material.

FIGURE 1 shows a section of the prism in one embodiment. The section has the shape of two isosceles trapeziums 3 and 4 having their small base in common.

FIGURE 2 is a section of the winding assembly in which the core is produced, in accordance with a variation, and in which the large base of the trapezium 3 is replaced by a quadrant presenting its concavity outwardly.

The angle formed by the sides 41 and 42 of the trapezium 4 is between 30 and 50°, and is preferably equal to 40°. This feature makes it possible, as will be seen below, to have the magnetic field gradient of great homogeneity for the quadripole.

FIGURE 3 is a view of the core in accordance with the embodiment of FIGURE 2. The end faces 5 and 6 of the metallic portion of the core are planar, the dihedral angle formed by their respective planes with a plane perpendicular to the generatrices of the prism being between 10 and 30°, preferably approximately 17°.

The metallic core is provided with two end pieces 7 and 8, preferably of plastic material and in particular, polytetrafluoroethylene, a polyamide (for instance, nylon) or polyethylene. These tips have substantially the shape of two truncated cones having the same axis and a common base, abutting on the planar end faces of the metallic element of the core. These tips are fixed to the metallic element, for instance, by screws, such as 9.

Referring FIGURE 2, it can be seen that the coil 10 can be manufactured by winding a superconductive cable around the core, parallel to the generatrices of the prism, in several layers. The core is mounted on the shaft of a winding machine by means of a central hole 50 having an axis perpendicular to the edges of the core and parallel to the plane of symmetry of the core. This winding is retained laterally, on the one hand by the sides 31 and 32 of the core, and on the other hand by side pieces 33 and 34, each constituted by a plurality of short rods 35 screwed in sequence onto each other, the first of them being fixed on a surface plane 37 formed at the base of the core.

The side pieces 33 and 34 are respectively parallel to the sides 31 and 32 and form between them an angle of 90°.

The metal of the core is preferably antimagnetic in order to avoid distorting the field produced by the winding as result of saturation phenomena.

Preferably, brass or duraluminum will be used for this purpose.

FIGURE 5 shows a coil assembly produced in the embodiment described above.

The cable constituting the winding is, for instance, a single strand insulated niobium-zirconium cable that can withstand a current strength of approximately 175 A./mm.².

The quadripole is formed by arranging four coils, such as are shown in FIGURE 5, their faces 30 facing each other and defining a cylindrical space. They are then assembled into a cylindrical shell.

FIGURE 4 shows a section of the quadripole through a plane perpendicular to its axis.

The cylindrical space is designated by the reference number 59.

The shell is preferably formed of four identical elements 61, 62, 63 and 64.

FIGURE 6 shows a perspective view of one such element. One coil, such as 71, 72, 73 and 74, is fixed to each element, together with its winding, by means of screws, such as 75.

The directions of the currents in the coils 71 to 74 are selected in such a way that the system is equivalent to four trapezoidal coils A, B, C, D with the opposed trapezoidal coils constituting two like poles, and the intervening coils constituting two unlike poles.

The directions of the currents are shown in FIGURE 4, where a sign + is the symbol for a current passing from the rear to the front of the plane of the sheet.

To take a concrete case, two end conductors J and K of the coils A, B, C, D are located at equal distance from the center O of the space 59. The distance separating the point O from the base of the line perpendicular to JK has the reference *b* and the distance JK has the reference *a*. Calculations show that the field gradient in the space 59 is most homogeneous if the ratio *a/b* is nearest to 0.5 for the greatest number of the conductors.

The trapezoidal form of the cores and of the coils, the way in which they are juxtaposed, and their dimensions make it possible to approach the theoretically ideal structures.

The elements of the shell are assembled together by rods and screws placed in bores, such as 76.

FIGURE 7 shows a perspective view of the quadripole in the course of assembly; three of the four coils are already assembled together and on the corresponding shell elements.

Hooping by means of steel cables arranged around the shell (not shown) ensures good mechanical rigidity for the unit as a whole.

The shell is closed at its ends by discs, preferably of soft iron (not shown), which restricts the leakage field of the quadripole.

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

What is claimed is:

1. An electric coil assembly for effecting magnetic field focusing within a quadripole structure comprising: a core including a metallic element of prismatic form and having a cross-section substantially in the form of two isosceles trapeziums with their small base in common, and an electric winding carried by said core and wound thereon parallel to the generatrices of the prism.

2. The assembly as claimed in claim 1 further including end pieces carried by said core on the end faces thereof.

3. The coil assembly as claimed in claim 1 wherein the angled sides for one of said trapeziums forms an acute angle on the order of 30 to 50°.

4. The coil assembly as claimed in claim 1 in which the large base of one of said trapeziums is arced to provide an exterior concave surface.

5. The assembly as claimed in claim 1 wherein each end face comprises a tip in the form of two coaxial truncated semicones attached together by their common small base.

6. The assembly as claimed in claim 1 wherein said end pieces are formed of a plastic material from the group comprising polytetrafluoroethylene, a polyamide and polyethylene.

7. The coil assembly as claimed in claim 1 further including means for laterally retaining said winding along its length, said means comprising side pieces along respective sides of said core, each side piece comprising a plurality of small rods of parallelepiped shape, forming a stack and means for coupling said stack to one edge of a trapezium.

8. The coil assembly as claimed in claim 1 wherein the configuration of said prism-shaped core is such that a dihedral angle is formed by the terminal face of the core with a plane perpendicular to the generatrices of the prism, said dihedral angle being in the order of 10 to 30°.

9. The coil assembly as claimed in claim 1 wherein the face of each side piece contacting the winding is parallel to the side of the other trapezium located on the same side of the core axis relative to the plane of symmetry of said core.

10. The coil assembly as claimed in claim 1 in which the core includes a central hole, the axis of which is perpendicular to the edges of the core and parallel to the plane of symmetry of the core.

11. The core assembly as claimed in claim 1 wherein said core comprises antimagnetic metal such as brass or duraluminum.

12. Quadripole with magnetic focusing comprising a metallic shell and four identical coil assemblies, each coil assembly comprising a core including a metallic element of prismatic form having a cross-section substantially in the form of two isosceles trapeziums with their small base in common, an electric winding wound on the core parallel to the generatrices of the prism, and means for circumferentially arranging said coil assembly such that the bases of the radially inner trapeziums define a space of substantially cylindrical shape.

13. The quadripole as claimed in claim 12 in which the shell is formed of four identical, joined shell elements and means for coupling the coil assemblies respectively to said elements.

14. The quadripole as claimed in claim 13 further including means for demountably coupling said shell elements together to form a cylindrical assembly.

15. The quadripole as claimed in claim 13 wherein the opposed sides between the large and small bases for one of said trapeziums form an acute angle on the order of 30 to 50°.

16. The quadripole as claimed in claim 15 further including end pieces coupled to respective end faces of said core, said end pieces being formed of a plastic material from the group comprising polytetrafluoroethylene, polyamide and polyethylene.

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GEORGE HARRIS, *Primary Examiner*.

U.S. Cl. X.R.

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