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(54) **Inductor**

Induktor

Inductance

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EP 1 655 745 B1

Description

FIELD OF THE INVENTION

[0001] The present invention relates to an inductor according to the preamble of independent claim 1.

[0002] A major application of a DC inductor as a passive component is in a DC link of AC electrical drives. Usual problems when designing inductors relate to their form and enclosure class.

[0003] An example of known inductor assembly is described in publication DE 19918322 A1 (closest prior art) that relates to a phase component for filter circuits, and describes an inductor according to the preamble of claim 1.

BRIEF DESCRIPTION OF THE INVENTION

[0004] An object of the present invention is to provide an inductor of a high enclosure class and reasonable manufacturing costs. The object of the invention is achieved by an inductor, which is characterized by what is stated in the characterizing part of independent claim 1. The preferred embodiments of the invention are disclosed in the dependent claims.

[0005] The invention is based on the idea of making the magnetic circuit of an inductor by combining ferromagnetic sheet material, substantially magnetically isotropic material, and a permanent magnet element.

[0006] Advantages of the inductor of the invention include a high enclosure class and reasonable manufacturing costs. A further advantage of the inductor of the invention is that its form can be quite freely chosen.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] In the following the invention will be described in greater detail by means of preferred embodiments with reference to the attached drawings, in which

Figure 1 is a sectional side view of an inductor according to an embodiment of the invention;

Figure 2 is a sectional top view taken along line A - A of the inductor of the Figure 1; and

Figure 3 is a diagram depicting stored magnetic field energy.

DETAILED DESCRIPTION OF THE INVENTION

[0008] Figure 1 shows a sectional side view of an inductor according to an embodiment of the invention. The inductor comprises a core 2 and a winding 4. The core 2 includes an inner core element 6 placed radially inside the winding 4 and an outer core element 8 placed radially outside the winding 4.

[0009] Both the inner core element 6 and the outer core element 8 have a form of a hollow cylinder. The inner 6 and the outer 8 core elements are manufactured

of a ferromagnetic sheet such, as a core sheet which is also known as a transformer sheet or a transformer plate. The ferromagnetic sheet is rolled into a spiral form in order to provide the tubular core element. Adjacent turns in the spiral are separated from one another by means of insulation therebetween. The spiral core element may be made by rolling a rectangular sheet blank into a cylindrical spiral shape.

[0010] The inner 6 and the outer 8 core elements made of ferromagnetic sheet material allow an elongated structure for the inductor because of the high mechanical strength of the material. The elongated shape of the inductor is an advantageous feature when the inductor has to be fitted in a casing having a small lateral dimension.

[0011] The winding 4 is relatively closely fitted between the inner core element 6 and the outer core element 8. Consequently, the inner diameter of the winding 4 is approximately the same as the outer diameter of the inner core element 6, and the outer diameter of the winding 4 is approximately the same as the inner diameter of the outer core element 8.

[0012] In the inner 6 and the outer 8 core elements the magnetic and thermal resistivity is lower in the direction parallel to the plane of the ferromagnetic sheet than in the direction perpendicular to the plane of the sheet. In other words, as regards the magnetic and thermal characteristics, the ferromagnetic sheet is an anisotropic material. This magnetic and thermal anisotropy is largely caused or at least increased by the insulation between the adjacent turns of the spirals. The magnetic anisotropy of the ferromagnetic sheet material is not a problem in the inductor according to the invention since the general direction of the magnetic flux in the inner core element 6 and in the outer core element 8 is parallel to the plane of the ferromagnetic sheet material.

[0013] The relative permeability of the ferromagnetic sheet material is approximately 3000 in a direction parallel to the plane and approximately 20 in a direction perpendicular to the plane.

[0014] The core 2 of the inductor further comprises a first end element 10 and a second end element 12 which are adapted to close the magnetic flux path in radial direction, adjacent to the first axial end 14 and the second axial end 16 of the winding 4, respectively. The axial direction of the winding 4 and the entire inductor is defined by the general direction of the magnetic flux inside the winding. The radial direction is a direction perpendicular to the axial direction.

[0015] The first end element 10 and the second end element 12 may be identical elements.

[0016] Each end element of the core 2 has an inner diameter that is equal to the inner diameter of the inner core element 6, and an outer diameter that is equal to the outer diameter of the outer core element 8. Substantially the entire magnetic flux of the inductor propagates through each of the end elements when the inductor is in use.

[0017] The core 2 of the inductor of Figure 1 has a

substantially constant cross sectional area. Therefore the distribution of the magnetic flux density B in the core 2 is also substantially constant.

[0018] The first end element 10 and the second end element 12 are made of soft magnetic composite material by powder metallurgy processes. The soft magnetic composites (SMC) are dielectromagnetic powder materials in which ferromagnetic particles are insulated from each other by a dielectric thermoset resin. The magnetic, electric and thermal properties of the soft magnetic composites (SMC) are isotropic.

[0019] There are several suitable soft magnetic composites commercially available for the realization of the inductor according to the invention. An example of a suitable material is Somaloy 550 + 0,5% Kenulube, manufactured by Höganäs AB, Sweden. The relative permeability of the above mentioned Somaloy material is approximately 250 in every direction.

[0020] Alternatively, the end elements 10 and 12 may be made of some other soft magnetic material or any other material that is substantially magnetically isotropic and has appropriate permeability.

[0021] The magnetic isotropy of the end elements 10 and 12 is an advantageous feature because the magnetic flux Φ makes substantially a 180° turn in each end element, as illustrated in Figure 1. Figure 1 also shows that the magnetic flux Φ propagates substantially exclusively in axial direction in the inner core element 6 and the outer core element 8.

[0022] Electric current and eddy currents generate heat and this heat has to be removed from the inductor. The inner 6 and the outer 8 core elements are thermally anisotropic, so they conduct heat better in the axial direction of the inductor. Therefore it is advantageous that also the end elements 10 and 12 have adequate thermal conductivity in the axial direction of the inductor. The thermal conductivity of the soft magnetic composites (SMC) is substantially similar to the thermal conductivity of the core sheet in the plane of the lamination, so the thermal conductivity of the soft magnetic composites is sufficiently high.

[0023] Figure 1 shows that in the end elements 10 and 12 the magnetic flux Φ and the heat flux Q propagate substantially perpendicularly relative to each other. It must be borne in mind that practically all anisotropic materials and structures have one direction or plane in which both magnetic and thermal resistivity are at their minimum. Consequently, if the end elements 10 and 12 were made of anisotropic material, either the magnetic flux Φ or the heat flux Q would have to propagate at least partly in an unfavourable direction as regards the material resistivity. Therefore it is advantageous that the material of the end elements is substantially isotropic both magnetically and thermally.

[0024] Figure 2 is a sectional top view taken along radial plane of the inductor of Figure 1. Figure 2 shows that the inner core element 6 and the outer core element 8 are mounted coaxially and that they both have a circular

cross section. Alternatively, the cross section of the inner core element 6 and the outer core element 8 may be elliptic or substantially rectangular, for example.

[0025] Figure 2 also shows that there is a round duct 28 provided in the centre of the inductor. The diameter of the duct 28 is equal to the inner diameter of the inner core element 6. The duct 28 extends through the inductor in the axial direction, and it may be utilized for cooling the inductor.

[0026] The components of the inductor may be held together by bolt inserted into the duct 28. The bolt and a corresponding nut may be arranged to press a first flange against the first axial end of the inductor and a second flange against the second axial end of the inductor. The bolt may be manufactured of plastic or other non-magnetic material.

[0027] It is also possible to provide an inductor that has both a bolt and a coolant channel in the duct 28. This may be achieved for example by a hollow bolt accommodating the coolant channel or by a coolant channel extending around the bolt and through the flanges.

[0028] The inductor of Figure 1 further comprises a permanent magnet element 20 provided in the magnetic circuit of the inductor. The permanent magnet element 20 is placed between the inner core element 6 and the first end element 10 such that at least a substantial portion of the magnetic flux Φ of the inductor propagates through the permanent magnet element 20 when the inductor is in use. Thus the permanent magnet element 20 is a core element of the inductor like the inner and outer core elements and the end elements.

[0029] The permanent magnet element 20 is inside the winding 4 in a radial direction. This way the size of the permanent magnet element 20 can be kept small, which is advantageous because suitable permanent magnet materials are expensive. Further, the inside of the winding 4 is a mechanically safer place than the outside of the winding.

[0030] The permanent magnet element 20 is an annular element. The inner and outer diameters of the permanent magnet element 20 are substantially the same as the inner and outer diameters of the inner core element 6, respectively.

[0031] The permanent magnet element 20 may be relatively thin. In one embodiment of the invention the thickness of the permanent magnet element 20 is approximately 0.5 mm.

[0032] Figure 3 shows how much magnetic field energy the inductor is able to store with and without the permanent magnet element 20. The magnetic flux density B is shown as a function of the direct current I_{dc} .

[0033] If there is no permanent magnet element 20 in the inductor and if no current is applied, the operating point of the inductor is P_{01} . When the inductor operates in the linear region of the BH curve, the operating point moves to P_1 for the magnetic flux density level B_w and DC current I_{dc} . The stored magnetic energy for the operating point P_1 is shown by the horizontally shaded area

in Figure 3.

[0034] Now, if the permanent magnet element 20 is inserted in the magnetic circuit, the starting point is P_{02} with the flux density $-B_0$ and zero current. When the current is supplied to the winding 4 the magnetomotive force generated by the current opposes the magnetization of the permanent magnet element 20. For the same value of direct current I_{dc} and with the same number of turns in the winding 4, the magnetic flux density B would not reach the value of B_w . This allows the number of turns in the winding 4 to be increased, by which the operating point P_1 can be reached. The stored energy is now shown as a sum of two shaded areas in Figure 3. The energy and thus the inductance has increased by the amount of the vertically shaded area when compared to the situation without the permanent magnet element 20. Therefore it is possible to decrease the size of an inductor of a predetermined inductance by fitting a permanent magnet element in the magnetic circuit of the inductor.

[0035] The permanent magnet element 20 facilitates the assembly of the inductor by holding the components of the inductor together by means of magnetic attraction. An example of a suitable material for the permanent magnet element 20 is NdFeB material NEOREM 499a, marketed by Neorem Magnets, Finland.

[0036] Referring to Figure 1, the inductor further comprises five magnetic seal elements that are adapted to improve the magnetic coupling between adjacent elements in the magnetic circuit of the inductor. The first one of these is denoted by reference numeral 18 and placed between the inner core element 6 and the second end element 12. The second one is denoted by reference numeral 19 and placed between the outer core element 8 and the second end element 12. The third one is denoted by reference numeral 22 and placed between the permanent magnet element 20 and the first end element 10. The fourth one is denoted by reference numeral 24 and placed between the permanent magnet element 20 and the inner core element 6. The fifth one is denoted by reference numeral 26 and placed between the outer core element 8 and the first end element 10. Each of the magnetic seal elements 18, 19, 22, 24 and 26 may be, for example, a solid element or an element formed by granular powder material or a semi-liquid element. The permeability of the material of each magnetic seal element is substantially higher than the permeability of air.

[0037] Due to the permanent magnet element 20 and the magnetic seal element 24, the inner core element 6 of the inductor of Figure 1 is slightly shorter in the axial direction than the outer core element 8.

[0038] The inductor according to the invention does not have to comprise magnetic seal elements. The magnetic seal elements may be replaced by a close fit between adjacent core elements.

[0039] The magnetic circuit of the inductor according to the present invention is a combination of inexpensive yet mechanically strong ferromagnetic sheet material in the inner and the outer core elements, substantially mag-

netically isotropic material in the end elements of the core, and a permanent magnet element. It will be obvious to a person skilled in the art that the inventive concept can be implemented in various ways. The invention and its embodiments are not limited to the examples described above but may vary within the scope of the claims.

10 Claims

1. An inductor comprising a core (2) and a winding (4), the core (2) including an inner core element (6) placed radially inside the winding (4) and an outer core element (8) placed radially outside the winding (4), both the inner core element (6) and the outer core element (8) being substantially tubular and made of ferromagnetic sheet material, wherein the core (2) further comprises a first end element (10) and a second end element (12) which are adapted to close the magnetic flux path in radial direction, adjacent to the first axial end (14) and the second axial end (16) of the winding (4), respectively, and the first end element (10) and the second end element (12) are made of material which is substantially magnetically isotropic, **characterized in that** there is a permanent magnet element (20) provided in the magnetic circuit of the inductor.
2. An inductor according to claim 1, **characterized in that** the material of the first (10) and the second (12) end element is also substantially thermally isotropic.
3. An inductor according to claim 2, **characterized in that** the material of the first (10) and the second (12) end element is a soft magnetic material.
4. An inductor according to any one of the preceding claims, **characterized in that** the first end element (10) and the second end element (12) are made by a powder metallurgy process.
5. An inductor according to any one of the preceding claims, **characterized in that** the inductor comprises a magnetic seal element (18) between two adjacent core elements (6, 12), the magnetic seal element (18) being adapted to improve the magnetic coupling between the two adjacent core elements (6, 12).
6. An inductor according to any one of the claims 1 to 5, **characterized in that** the permanent magnet element (20) is placed between the inner core element (6) and one of the end elements (10).
7. An inductor according to claim 6, **characterized in that** the inductor comprises a magnetic seal element (22, 24) on both sides of the permanent magnet el-

ement (20), the seal elements (22, 24) being adapted to improve the magnetic coupling between the permanent magnet element (20) and the adjacent core elements (6, 10).

8. An inductor according to any one of the preceding claims, **characterized in that** the core (2) of the inductor is arranged such that, when in use, the magnetic flux (Φ) propagates substantially exclusively in axial direction in the inner core element (6) and the outer core element (8).

Patentansprüche

1. Induktor, der einen Kern (2) und eine Wicklung (4) umfasst, wobei der Kern (2) ein inneres Kernelement (6), das radial im Inneren der Wicklung (4) platziert ist und ein äußeres Kernelement (8), das radial außerhalb der Wicklung (4) platziert ist einschließt, und wobei sowohl das innere Kernelement (6) als auch das äußere Kernelement (8) im Wesentlichen röhrenförmig sind und aus einem ferromagnetischen Blechmaterial hergestellt sind, wobei der Kern (2) ferner ein erstes Abschlusselement (10) und ein zweites Abschlusselement (12) umfasst, die eingerichtet sind, um jeweils den Magnetflusspfad in der radialen Richtung in der Nachbarschaft des ersten axialen Endes (14) und des zweiten axialen Endes (16) der Wicklung (4) abzuschließen und wobei das erste Abschlusselement (10) und das zweite Abschlusselement (12) aus einem Material hergestellt sind, das im Wesentlichen magnetisch isotrop ist, **dadurch gekennzeichnet, dass** ein Permanentmagnetelement (20) in dem Magnetkreis des Induktors vorgesehen ist
2. Induktor nach Anspruch 1, **dadurch gekennzeichnet, dass** das Material des ersten (10) und des zweiten (12) Abschlusselements ebenfalls im Wesentlichen thermisch isotrop ist.
3. Induktor nach Anspruch 2, **dadurch gekennzeichnet, dass** das Material des ersten (10) und des zweiten (12) Abschlusselements ein weichmagnetisches Material ist.
4. Induktor nach irgendeinem der vorausgehenden Ansprüche, **dadurch gekennzeichnet, dass** das erste Abschlusselement (10) und das zweite Abschlusselement (12) durch einen Pulvermetallurgieprozess hergestellt werden.
5. Induktor nach irgendeinem der vorausgehenden Ansprüche, **dadurch gekennzeichnet, dass** der Induktor ein magnetisches Abdichtungselement (18) zwischen zwei benachbarten Kernelementen (6, 12) umfasst, wobei das magnetische Abdichtungsele-

ment (18) eingerichtet ist, um die magnetische Kopplung zwischen zwei benachbarten Kernelementen (6, 12) zu verbessern.

- 5 6. Induktor nach irgendeinem der Ansprüche 1 bis 5, **dadurch gekennzeichnet, dass** das Permanentmagnetelement (20) zwischen dem inneren Kernelement (6) und einem der Abschlusselemente (10) angebracht ist
- 10 7. Induktor nach Anspruch 6, **dadurch gekennzeichnet, dass** der Induktor ein magnetisches Abdichtungselement (22, 24) zu beiden Seiten des Permanentmagnetelements (20) umfasst, wobei die Abdichtungselemente (22, 24) eingerichtet sind, um die magnetische Kopplung zwischen dem Permanentmagnetelement (20) und den benachbarten Kernelementen (6, 10) zu verbessern.
- 15 8. Induktor nach irgendeinem der vorausgehenden Ansprüche, **dadurch gekennzeichnet, dass** der Kern (2) des Induktors auf eine solche Weise angeordnet ist, dass, wenn er in Verwendung ist, sich der magnetische Fluss (Φ) im Wesentlichen ausschließlich in axialer Richtung in dem inneren Kernelement (6) und dem äußeren Kernelement (8) ausbreitet.
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Revendications

- 30 1. Inductance comprenant un noyau (2) et un enroulement (4), le noyau (2) comprenant un élément de noyau intérieur (6) placé radialement à l'intérieur de l'enroulement (4) et un élément de noyau extérieur (8) placé radialement à l'extérieur de l'enroulement (4), l'élément de noyau intérieur (6) et l'élément de noyau extérieur (8) étant tous deux sensiblement tubulaires et réalisés en un matériau en feuille ferromagnétique, dans laquelle le noyau (2) comprend en outre un premier élément d'extrémité (10) et un deuxième élément d'extrémité (12) qui sont adaptés pour fermer le trajet de flux magnétique dans la direction radiale, respectivement adjacents à la première extrémité axiale (14) et à la deuxième extrémité axiale (16) de l'enroulement (4), et le premier élément d'extrémité (10) et le deuxième élément d'extrémité (12) sont réalisés en un matériau qui est sensiblement magnétiquement isotrope, **caractérisée en ce qu'un** élément d'aimant permanent (20) est prévu dans le circuit magnétique de l'inductance.
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- 40 2. Inductance selon la revendication 1, **caractérisée en ce que** le matériau des premier (10) et deuxième (12) éléments d'extrémité est également sensiblement thermiquement isotrope.
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- 50 3. Inductance selon la revendication 2, **caractérisée en ce que** le matériau des premier (10) et deuxième
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(12) éléments d'extrémité est un matériau magnétique doux.

4. Inductance selon l'une quelconque des revendications précédentes, **caractérisée en ce que** le premier élément d'extrémité (10) et le deuxième élément d'extrémité (12) sont réalisés par un processus de métallurgie des poudres. 5

5. Inductance selon l'une quelconque des revendications précédentes, **caractérisée en ce que** l'inductance comprend un élément d'étanchéité magnétique (18) entre deux éléments de noyaux (6, 12) adjacents, l'élément d'étanchéité magnétique (18) étant adapté pour améliorer le couplage magnétique entre les deux éléments de noyaux (6, 12) adjacents. 10
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6. Inductance selon l'une quelconque des revendications 1 à 5, **caractérisée en ce que** l'élément d'aimant permanent (20) est placé entre l'élément de noyau intérieur (6) et l'un des éléments d'extrémité (10). 20

7. Inductance selon la revendication 6, **caractérisée en ce que** l'inductance comprend un élément d'étanchéité magnétique (22, 24) des deux côtés de l'élément d'aimant permanent (20), les éléments d'étanchéité (22, 24) étant adaptés pour améliorer le couplage magnétique entre l'élément d'aimant permanent (20) et les éléments de noyau (6, 10) adjacents. 25
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8. Inductance selon l'une quelconque des revendications précédentes, **caractérisée en ce que** le noyau (2) de l'inductance est agencé de sorte que, en fonctionnement, le flux magnétique (Φ) se propage sensiblement exclusivement dans la direction axiale dans l'élément de noyau intérieur (6) et l'élément de noyau extérieur (8). 35

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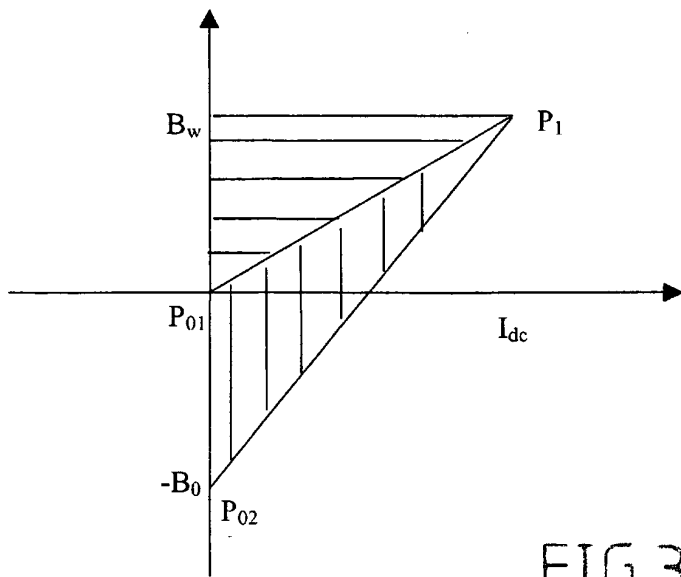
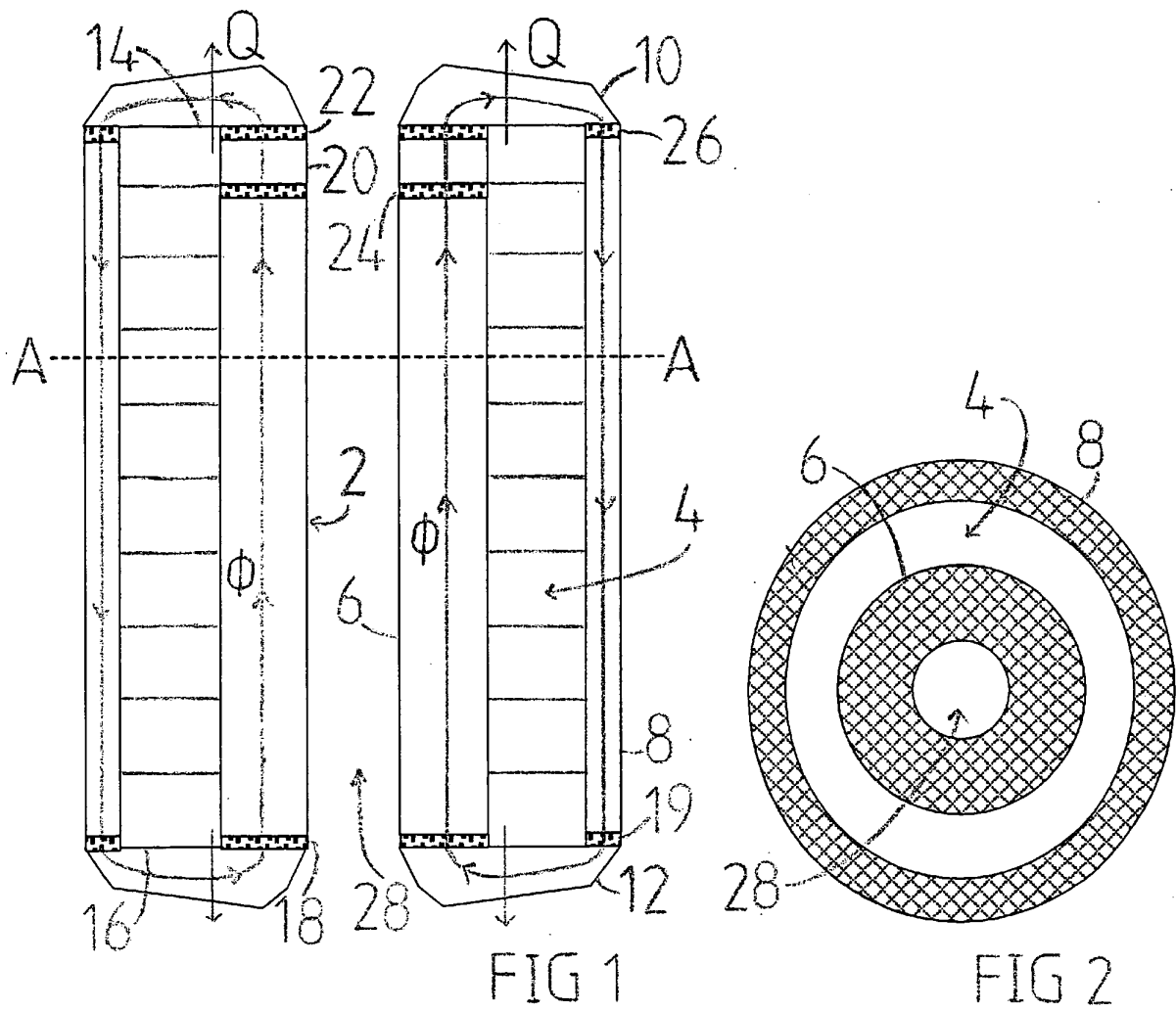


FIG 3