(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 655 745 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
10.05.2006 Bulletin 2006/19

(51) Int Cl.:
H01F 3/10 *(2006.01)* ***H01F 38/02*** *(2006.01)*

(21) Application number: **04105616.9**

(22) Date of filing: **09.11.2004**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LU MC NL PL PT RO SE SI SK TR
Designated Extension States:
AL HR LT LV MK YU

(71) Applicant: **ABB Oy**
00380 Helsinki (FI)

(72) Inventors:
- **Arkkio, Antero**
  02130 Espoo (FI)
- **Saitz, Julius**
  02650 Espoo (FI)
- **Södö, Nicklas**
  02760 Espoo (FI)
- **Virolainen, Panu**
  02230 Espoo (FI)

(74) Representative: **Valkeiskangas, Tapio Lassi Paavali**
Kolster Oy AB
Iso Roobertinkatu 23, P.O. Box 148
00121 Helsinki (FI)

Remarks:
•Amended claims in accordance with Rule 86 (2) EPC.
•A request for correction in the description has been filed pursuant to Rule 88 EPC. A decision on the request will be taken during the proceedings before the Examining Division (Guidelines for Examination in the EPO, A-V, 3.).

(54) Inductor

(57) 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. 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 the first axial end (14) and the second axial end (16) of the winding (4), respectively, and in that the first end element (10) and the second end element (12) are made of material which is substantially magnetically isotropic.

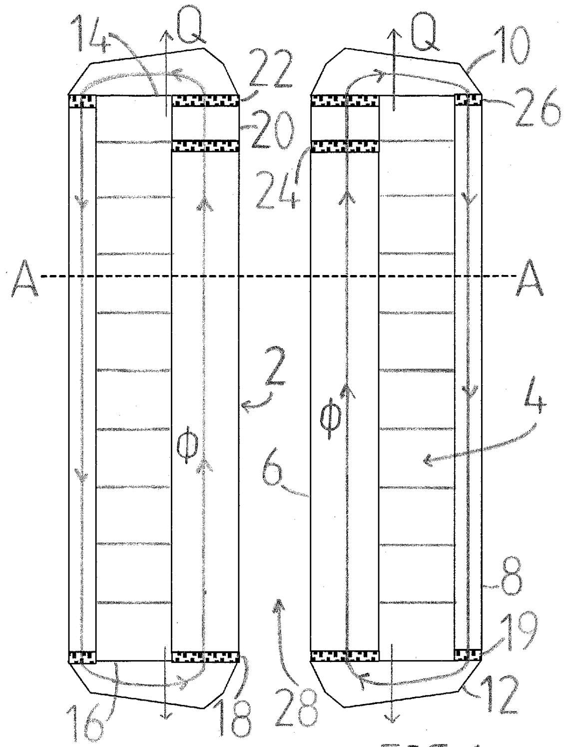

FIG 1

EP 1 655 745 A1

Description

FIELD OF THE INVENTION

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

BRIEF DESCRIPTION OF THE INVENTION

[0003] An object of the present invention is to provide an inductor with 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.

[0004] The invention is based on the idea of making the magnetic circuit of an inductor by combining ferromagnetic sheet material and substantially magnetically isotropic material.

[0005] An advantage of the inductor of the invention is that it has high enclosure class and reasonable manufacturing costs. Further advantage of the inductor of the invention is that its form can be quite freely chosen.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] In the following the invention will be described in greater detail by means of preferred embodiments with reference to the attached drawings, in which

[0007] Figure 1 is a sectional side view of an inductor according to an embodiment of the invention;

[0008] Figure 2 is a sectional top view taken along line A - A in the inductor of the figure 1; and

[0009] Figure 3 is a diagram depicting stored magnetic field energy.

DETAILED DESCRIPTION OF THE INVENTION

[0010] 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.

[0011] 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 ferromagnetic sheet such as core sheet, which is also known as transformer sheet or transformer plate. The ferromagnetic sheet is rolled into 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 cylindrical spiral shape.

[0012] The inner 6 and the outer 8 core elements made out 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.

[0013] 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 same as the outer diameter of the inner core element 6, and the outer diameter of the winding 4 is approximately same as the inner diameter of the outer core element 8.

[0014] 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 the ferromagnetic sheet is an anisotropic material as regards the magnetic and thermal characteristics. 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.

[0015] Relative permeability of the ferromagnetic sheet material is approximately 3000 parallel to the plane and approximately 20 perpendicular to the plane.

[0016] 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 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.

[0017] The first end element 10 and the second end element 12 may be identical elements.

[0018] 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 entire magnetic flux of the inductor propagates through each of the end elements when the inductor is in use.

[0019] 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.

[0020] 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.

[0021] 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. Relative permeability of the above mentioned Somalloy material is approximately 250 in every direction.

[0022] 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.

[0023] 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 the 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.

[0024] 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 core sheet in the plane of the lamination, so the thermal conductivity of the soft magnetic composites is sufficiently high.

[0025] Figure 1 shows that in the end elements 10 and 12 the magnetic flux Φ and the heat flux Q propagate substantially perpendicular 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 has its 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.

[0026] Figure 2 is a sectional top view taken along radial plane of the inductor of the 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.

[0027] 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.

[0028] The components of the inductor may be held together by bolt i n-serted 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 out of plastic or other non-magnetic material.

[0029] It is also possible to provide an inductor that has in the duct 28 both a bolt and a coolant channel. 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.

[0030] 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 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 inner and outer core elements and the end elements.

[0031] 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 mechanically safer place than the outside of the winding.

[0032] The permanent magnet element 20 is an annular element. The inner and outer diameters of the permanent magnet element 20 are substantially same as the inner and outer diameters of the inner core element 6, respectively.

[0033] 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.

[0034] 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}-

[0035] If there is no permanent magnet element 20 in the inductor and if no current is applied, the operating point is P_{01}. Operating 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 given by the horizontally shaded area in figure 3.

[0036] 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 for the increase in the number of turns in the winding 4, by which the operating point P_1 can be reached. The stored energy is now given as a sum of two shaded areas in figure 3. The energy and thus the inductance has increased when compared to the case without permanent magnet element 20 by amount of the vertically shaded area. 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.

[0037] 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.

[0038] 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.

[0039] The inner core element 6 of the inductor of figure 1 is slightly shorter in the axial direction than the outer core element 8. This is caused by the existence of permanent magnet element 20 and the magnetic seal element 24.

[0040] The inductor according to the invention does not have to comprise magnetic seal elements. The magnetic seal elements may be replaced by close fit between adjacent core elements.

[0041] 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, and substantially magnetically isotropic material in the end elements of the core. 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.

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, **characterized in that** 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 the first axial end (14) and the second axial end (16) of the winding (4), respectively, and **in that** the first end element (10) and the second end element (12) are made of material which is substantially magnetically isotropic.

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 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 preceding claims, **characterized in that** there is a permanent magnet element (20) provided in the magnetic circuit of the inductor, the permanent magnet element (20) being placed preferably inside the winding (4) in the radial direction.

7. An inductor according to claim 6, **characterized in that** the permanent magnet element (20) is placed between the inner core element (6) and one of the end elements (10).

8. An inductor according to claim 7, **characterized in that** the inductor comprises a magnetic seal element (22, 24) on both sides of the permanent magnet element (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).

9. 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).

Amended claims in accordance with Rule 86(2) EPC.

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 element (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).

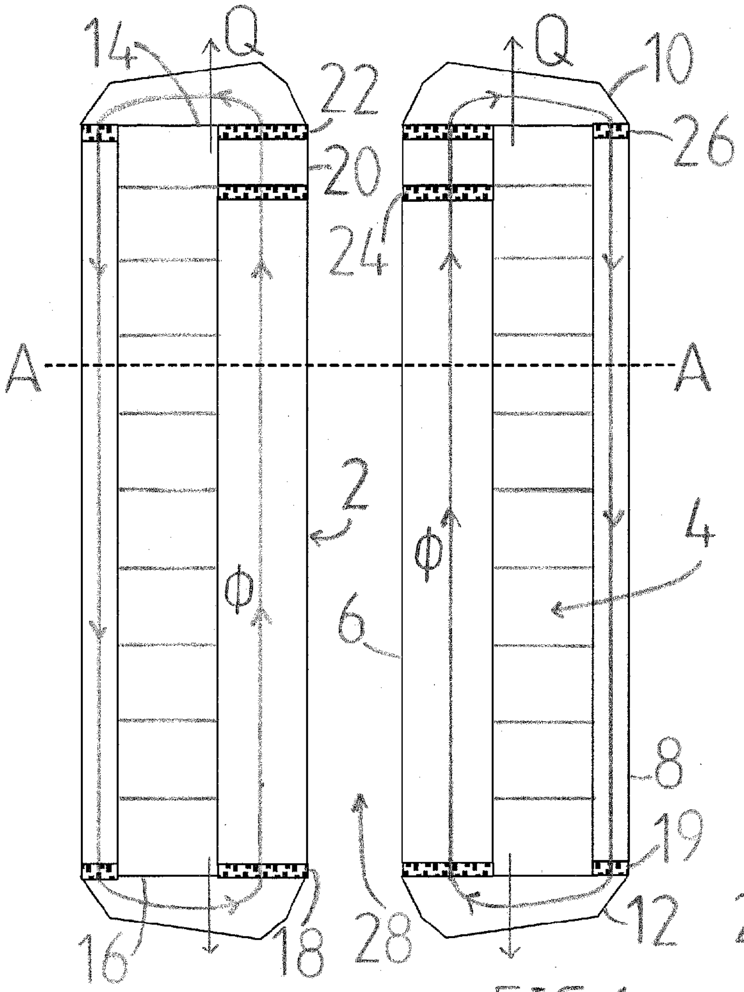

FIG 1

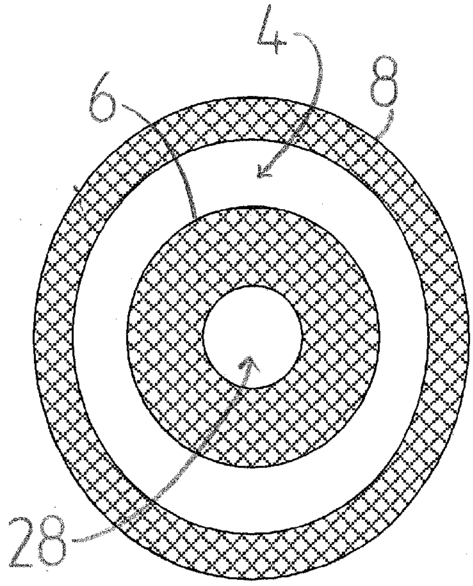

FIG 2

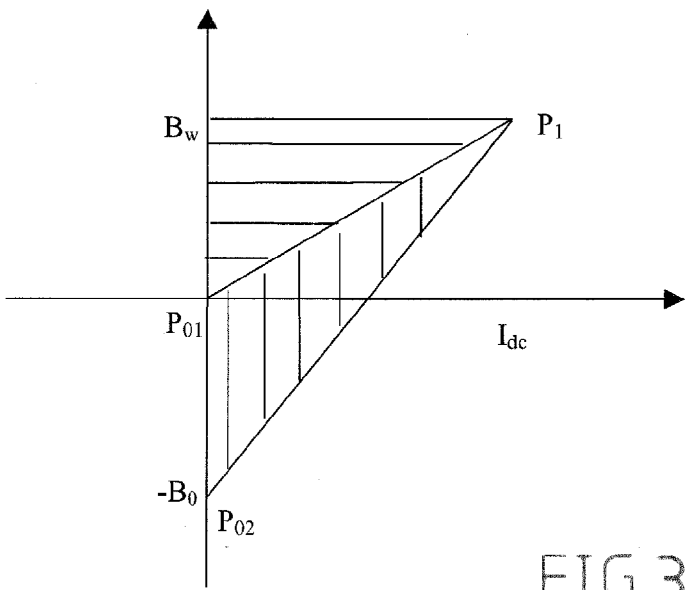

FIG 3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 04 10 5616

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	DE 199 18 322 A1 (EPCOS AG) 16 November 2000 (2000-11-16) * claims 1,6-9 * * column 4, lines 4-9 * * figures 1,3 * -----	1,3,4,9	H01F3/10 H01F38/02
A	EP 0 157 669 A (IMPHY S.A) 9 October 1985 (1985-10-09) * claims 1,2,9-12 * * page 5, line 36 - line 38 * * figure 1 * -----	1-3,9	
			TECHNICAL FIELDS SEARCHED (Int.Cl.7)
			H01F

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	11 April 2005	Stichauer, L

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
....
& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 04 10 5616

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

11-04-2005

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 19918322 A1	16-11-2000	NONE	
EP 0157669 A	09-10-1985	FR 2560711 A1	06-09-1985
		AT 29331 T	15-09-1987
		DE 3560540 D1	08-10-1987
		EP 0157669 A1	09-10-1985
		ES 8700791 A1	16-01-1987
		ZA 8501595 A	30-10-1985

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82