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(54) Inductive device.

(57) The device comprises at least a winding (31) and a core which is made of a soft-magnetic material and which comprises at least two portions (1, 3), each of which includes an air gap forming portion (9, 11), said air gap forming portions having first surfaces (13, 15) which face one another so that an air gap (17) exists between the first surfaces, the configuration being such that the core forms a closed magnetic circuit, the magnetic reluctance of the air gap being substantially greater than that of the core portions consisting of a soft-magnetic material. In order to reduce the adverse effects of leakage fields at the fringes of the air gap (17), the principal direction of magnetic lines of force (35) in the air gap (17) encloses, at least near the fringes of the air gap, an angle of at least 45° relative to the principal direction of magnetic lines of force (33) in the air gap forming portions (9, 11) of the core. To this end, each air gap forming portion (9, 11) preferably contains a axis (23) whereto the principal direction of the magnetic lines of force (33) in the relevant portion extends approximately parallel, the normal (25, 27) to each of the first surfaces (15, 17) of each air gap forming portion enclosing an angle of at least 45° relative to said axis.

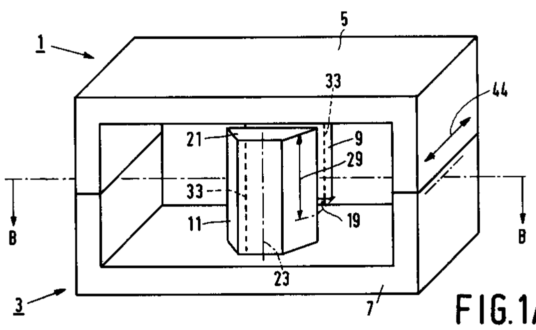

FIG.1A

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The invention relates to a inductive device, comprising at least a winding ad a core which is made of a soft-magnetic material and which comprises at least two portions, each of which comprises a air gap forming portion, which air gap forming portions comprise first surfaces which face one another so that a air gap exists between the first surfaces, the configuration being such that the core forms a closed magnetic circuit, the magnetic reluctance of the air gap being substantially greater than that of the core portions consisting of a soft-magnetic material.

An example of such a device is known from EP-A-0 385 220. It is a drawback of inductive devices (for example, coils or transformers) comprising a air gap that magnetic leakage fields occur at the fringe of the air gap, which leakage fields can cause, notably when the winding surrounds the air gap, eddy currents in the winding so that the temperature of the winding could become very high. In the known device this drawback is somewhat mitigated in that the air gap forming portions are shaped so that near the fringes of the air gap the facing first surfaces are removed further from one another than in the vicinity of the centre. As a result, the magnetic field in the air gap is strongest at the centre, so that the leakage field occurring at the fringe is comparatively weak. However, it has been found that the improvement thus achieved is not always adequate.

It is an object of the invention to provide a device of the kind set forth which enables a further reduction of the detrimental effects of the leakage field at the fringe of the air gap.

To achieve this, the device in accordance with the invention is characterized in that the principal direction of magnetic lines of force in the air gap encloses, at least near the fringes of the air gap, a angle of at least 45° relative to the principal direction of magnetic lines of force in the air gap forming portions of the core.

A major advantage of the device in accordance with the invention consists in that the leakage field now extends parallel or substantially parallel to the electrically conductive surfaces of the neighbouring portions of the winding, so that the occurrence of eddy currents is strongly reduced.

Said course of the magnetic lines of force is achieved by means of comparatively simple structural steps in a embodiment which is characterized in that each air gap forming portion contains a axis whereto the principal direction of the magnetic lines of force in the relevant portion is approximately parallel, the normal to each of the first surfaces of each air gap forming portion enclosing an angle of at least 45° relative to said axis.

A preferred embodiment of the device in accordance with the invention is characterized in that each air gap forming portion comprises a free end and an end which is connected to the relevant portion of the core, the axis extending from the connected end to the free end, the cross-section of the air gap forming portions being substantially smaller near their free end than near their connected end. This embodiment offers the advantage that the magnetic flux density in the air gap forming portions is substantially constant over the entire length of said portions.

A further embodiment is characterized in that the air gap forming portions also comprise second surfaces which are oriented, in the vicinity of the fringes of the air gap, so that the normals to the parts of the second surfaces extending to both sides of the air gap enclose an angle of more than 0° relative to one another. As a result of this step, the magnetic lines of force between the parts of the second surfaces which adjoin the air gap describe an arc of more than 180°, so that the leakage field is substantially attenuated even further. A further attenuation of this leakage field is achieved when near the fringes of the air gap the second surfaces are oriented so that the normals to the parts of the second surfaces extending to both sides of the air gap enclose an angle of at least 90° relative to one another. In that case the magnetic lines of force describe an arc of more than 270°.

The leakage field is further reduced when the width of the air gap is greater near the fringes of the air gap than near the central portion thereof.

In some cases it is desirable for the width of the air gap to be adjustable. To this end, a further embodiment of the device in accordance with the invention is characterized in that there are provided adjusting means for adjusting the distance between the facing first surfaces. The adjusting means preferably comprise a adjusting screw.

The invention will be described in detail hereinafter with reference to the drawing.

Figs. 1A, 1B are a perspective view and a cross-sectional view, respectively, of a core of a first embodiment of a device in accordance with the invention,

Fig. 2A is a perspective view of a part of a second embodiment,

Fig. 2B is a longitudinal sectional view of the second embodiment,

Figs. 2C and 2D are longitudinal sectional views of parts of versions of the second embodiment,

Figs. 2E and 2F are perspective views of two further versions of the second embodiment,

Figs. 3 to 6 are cross-sectional views of parts of four further embodiments,

Figs. 7 and 8 are perspective views of parts of a seventh and an eighth embodiment, respectively,

Fig. 9 is a perspective view of parts of a ninth embodiment, and

Figs. 10A and 10B are a longitudinal sectional view and a cross-sectional view, respectively, of a tenth embodiment.

Fig. 1A is a perspective view of a core, made of a soft-magnetic material (for example, ferrite), for a first embodiment of an inductive device (for example, a transformer or choke coil) in accordance with the invention. The core consists of two portions 1 and 3 which are approximately E-shaped and each of which comprises an approximately U-shaped yoke 5, 7, respectively, and a rod-shaped limb 9, 11, respectively. The limbs 9, 11 serve as the air gap forming portions of the core. Both limbs comprise a first surface 13, 15, respectively, which face one another and wherebetween an air gap 17 is present as appears from the cross-sectional view of Fig. 1B. Each of the core portions 1, 3 is an integral unit formed from the core material and each limb 9, 11 comprises an end which is connected to the associated yoke 5, 7 and a free end 19, 21. Each limb 9, 11 also has an axis which extends from the connected end to the free end 19, 21. In Fig. 1A the axis 23 of the limb 11 is denoted by a dash-dot line. The axis of the limb 9 (not shown) extends parallel to the axis 23 of the limb 11. The first surfaces 13, 15 of the present embodiment extend parallel to the axes of the limbs 9, 11. The normals 25, 27 to said surfaces, therefore, enclose an angle of 90° relative to the axes of the limbs 9, 11. The length of the limbs 9, 11 is chosen so that the free end 19, 21 does not contact the yoke 7, 5 associated with the other core portion. The limbs 9, 11 overlap one another over the major part of their length. The degree of overlap, co-determining the transverse dimension of the air gap, is denoted by a double arrow 29 in Fig. 1A. The core constitutes a closed magnetic circuit, the magnetic reluctance of the air gap 17 being substantially greater than that of the core portions consisting of a soft-magnetic material.

An electric current in a winding 31 which is diagrammatically shown in Fig. 1B and which encloses the limbs 9, 11 causes a magnetic field in the limbs, the lines of force 33 (denoted by dashed lines in Fig. 1A) of said magnetic field extending mainly parallel to the axes 23 of the limbs. In the air gap 17 the magnetic lines of force 35 (also denoted by dashed lines in Fig. 1B) extend mainly perpendicularly to the first surfaces 13, 15 and hence parallel to the normals 25, 27. Because the normals 25, 27 extend perpendicularly to the axes 23, the principal direction of the magnetic lines of force 35 in the air gap 17 also extends perpendicularly to the principal direction of the magnetic lines of force 33 in the air gap forming portions (the limbs 9, 11) of the core. Consequently, the magnetic lines of force 35' of the leakage field near the fringes of the air gap 17 extend substantially parallel to the electrically conductive surface of the winding 31. Therefore, this leakage field will cause only insignificant eddy currents in the winding 31.

The limbs 9, 11 also comprise second surfaces 37, 39 which, near the fringes of the air gap 17, are oriented so that the normals 41, 43 to the parts of said second surfaces which extend to both sides of the air gap enclose an angle of more than 0° (approximately 90° in the present embodiment) relative to one another. As a result, the magnetic fines of force 35' of the leakage field describe an arc of at least 180° (approximately 270° in the present embodiment), so that they must bridge a comparatively large distance so that the leakage field is attenuated.

If desired, the width of the air gap 17 can be adjusted by displacement of the two core portions 5, 7 in the direction of the double arrow 44 relative to one another. When the desired air gap width is reached, the core portions 5, 7 can be rigidly connected to one another, for example by means of an adhesive.

In the embodiment shown in the Figs. 1A and 1B the cross-section of the limbs 9, 11 is substantially constant over their entire length. As a result, the density of the magnetic flux in the limbs 9, 11 gradually decreases from the connected end to the free end. It is generally attempted to keep the flux density in the core material as constant as possible. A substantially constant flux density in the air gap forming portions of the core can be achieved in the device in accordance with the invention in that the cross-section of these portions decreases gradually in the direction from the connected end towards the free end. Fig. 2A shows a example of a core portion where this is the case. This Figure shows a core portion 3' with a yoke 7' ad an air gap forming portion (limb) 45. The limb 45 is shaped as a obliquely cut circular cylinder whose smallest cross-section is situated at the free end 47.

Fig. 2B is a longitudinal sectional view of a core which is composed of a first core portion 3' as shown in Fig. 2A and a second core portion 5' which comprises a correspondingly shaped limb 49 having a free end 51. This core is mounted in a diagrammatically shown frame 53 in which adjusting screws 55, 57 ad 59 are provided. The adjusting screws 55 and 57 engage the core portions 3' and 5', respectively, and move these core portions towards one another when they are screwed in. The third adjusting screw 59 engages the limb 49 and moves this limb away from the limb 45 when it is tightened. So as not to impede the movement of the first core portion 3' induced by the adjusting screw 57, the adjusting screw 59 extends *via* an elongate opening 60 in the frame 53, so that it can move to the left and to the right in Fig. 2B. The air gap 17' can be simply adjusted by means of these adjusting screws: when the adjusting screws 55, 57 are loosened and the adjusting screw 59 is tightened, the width of the air gap is increased; the width is decreased by reversing these operations. If necessary, the use of only the adjusting screws 55 and 57 or only the adjusting screw 59 suffices when use is made of suitable springs which press the core portions 3', 5, towards one another (not shown).

Figs. 2C and 2D diagrammatically illustrate feasible modifications of the shape of the limbs shown in Fig. 2B, the flux density then being comparatively high near the free ends, so that the core material is comparatively easily saturated at those areas. This effect is achieved in that the air gap is narrower near the free ends than at the centre. To this end, the limbs 45', 49' shown in Fig. 2C are step-wise thickened near their free ends 47', 51', the limbs 45'', 49'' shown in Fig. 2D have a cross-section which decreases less rapidly near their free ends 47'', 51'' than in the vicinity of the connected ends.

In the modifications shown in the Figs. 2E and 2F the air gap extends into the yoke. In Fig. 2E the cross-section of the limb 45''' gradually decreases over the entire length of the limb and in Fig. 2F the cross-section is constant over a part of the length. In both cases the width w_1 near the free end of the limb 45''' or 45'''' should be smaller than the width w_2 of the opening 8 recessed in the yoke 7''' or 7'''', respectively. These modifications offer the advantage that the winding can extend as far as the yoke, provided that this is permitted by the insulation requirements.

In the embodiment shown in the Figs. 2A and 2B, the cross-section of the limbs 45, 49 gradually decreases in the direction of the free end. The leakage field at the fringe of the air gap does not extend exactly perpendicularly to the axes of the limbs. This drawback can be mitigated by making the facing surfaces of the limbs extend parallel to the axis near the fringes of the air gap and by realising the variation of the cross-section in the vicinity of the centre of the air gap. Figs. 3 to 6 show some examples in this respect. Each of the Figures shows three cross-sections of the limbs: at A near the connected end of the first limb 61, at B approximately halfway between the free end and the connected end of the limbs, and at C near the connected end of the second limb 63. The variation of the cross-section at the central part of the air gap may be gradual or stepped. The normals to the parts of the second surfaces extending to both sides of the air gap 65 are denoted by the reference numerals 67 and 69. The Figures show that the facing first surfaces are shaped so that the width of the air gap 65 is greater near the fringes of the air gap than in the vicinity of the central part thereof.

In Fig. 3 the cross-section of the two limbs taken together is shaped approximately as a square and the normals 67, 69 enclose an angle of 90° relative to one another. In Fig. 4 the cross-section of the two limbs taken together is shaped approximately as a rectangle. The normals 67, 69 again enclose a angle of 90° relative to one another. In Fig. 5 the cross-section of the two limbs taken together is shaped approximately as a circle and the normals 67, 69 enclose an angle of slightly more than 0° relative to one another. In Fig. 6 the cross-section of the two limbs taken together has an oval shape and the normals 67, 69 enclose an angle of more than 90° relative to one another.

In the embodiments shown in the Figs. 3 to 6 the width of the central part of the air gap 65 is substantially constant over the entire length of the limbs 61, 63. However, it may be advantageous to make a part of the air gap 65 which is situated between the two ends of the limbs 61, 63 wider than the parts situated near the ends. This is the case notably when the winding does not extend as far as the ends of the limbs 61, 63, for example because the winding is to remain a given distance from the yokes for the sake of suitable insulation between the winding and the core. The narrow (active) parts of the air gap 65, having the strongest leakage fields, are then situated outside the winding, so that the leakage fields can hardly cause eddy currents in the winding.

Figs. 7 and 8 are perspective views of two feasible embodiments of the limb 61 where the part of the air gap situated between the ends is wider than the parts situated near the ends.

Fig. 7 shows a modification of the embodiment shown in Fig. 4 and Fig. 8 shows a modification of the embodiment shown in Fig. 5. In both cases a recess 71 is provided in the central portion of the limb 61, so that at that area the surfaces 73 are spaced apart further than near the end portions.

Fig. 9 is a perspective view of parts of an inductive device comprising a so-called H+O core constructed in accordance with the invention. An H+O core consists of an approximately H-shaped portion and an approximately O-shaped portion, for example as described in US-A-3 189 859. Fig. 9 shows a part of the O-shaped portion 77, a part of the H-shaped portion 79 and a part of a winding 81 wound from a strip-shaped electrical conductor. Each of the two core portions 77, 79 comprises an air gap forming portion 83, 85, respectively, having a first surface 87, 89, respectively. The principal direction of the magnetic lines of force in the two core portions is denoted by the dashed lines 91, 93, respectively. It appears that the magnetic flux in the first air gap forming portion 83 decreases in the direction from the ends towards the centre and that in the second air gap forming portion 85 it increases in the direction from the ends towards the centre. The variation of the flux thus corresponds to the variation in two limbs 63 or 65 whose free ends are arranged one against the other, for example as shown in Fig. 4. The shape of the first surface 87 of the first air gap forming portion 83, therefore, is chosen so that the cross-section of this portion is greatest near the ends and smallest near the centre. The first surface 89 of the second air gap forming portion 85 has a complementary shape.

Fig. 10A is a longitudinal sectional view and Fig. 10B is a cross-sectional view of an embodiment of an inductive device in accordance with the invention in which a so-called pot core is used. Such a core consists of two portions 95, 97 in the form of a cylinder having an axis 98 and being closed at one end by a flat bottom, and comprises an air gap forming portion 99, 101 extending perpendicularly to the bottom. The air gap forming portions 99, 101 have axes which coincide with the cylinder axis 98. The first air gap forming portion 99 is shaped approximately as a semi-cylinder 103 with a half cone 105 which is arranged against its flat face and which extends from the bottom to halfway its height, and a semi-conical recess 107 which widens in the direction upwards from the apex of the cone. The second air gap forming portion 101 has a complementary shape and the air gap 109 extends between said portions approximately as shown in Fig. 5. At the fringe of the air gap 109 the magnetic lines of force 111 (denoted by dashed lines) extend perpendicularly to the axis 98 and hence perpendicularly to the principal direction of the magnetic lines of force in the air gap forming portions 99, 101. The device comprises a winding 113 in the form of printed circuit boards. The magnetic lines of force 111 of the leakage fields extend parallel to the electrically conductive surface thereof.

Claims

1. An inductive device, comprising at least a winding (31) and a core which is made of a soft-magnetic material and which comprises at least two portions (1, 3), each of which comprises an air gap forming portion (9, 11), which air gap forming portions comprise first surfaces (13, 15) which face one another so that an air gap (17) exists between the first surfaces, the configuration being such that the core forms a closed magnetic circuit, the magnetic reluctance of the air gap being substantially greater than that of the core portions consisting of a soft-magnetic material, characterized in that the principal direction of magnetic lines of force (35) in the air gap (17) encloses, at least near the fringes of the air gap, a angle of at least 45° relative to the principal direction of magnetic lines of force (33) in the air gap forming portions (9, 11) of the core.

2. A device as claimed in Claim 1, characterized in that each air gap forming portion (9, 11) contains an axis (23) whereto the principal direction of the magnetic lines of force (33) in the relevant portion is approximately parallel, the normal (25, 27) to each of the first surfaces (15, 17) of each air gap forming portion enclosing an angle of at least 45° relative to said axis.

3. A device as claimed in Claim 2, characterized in that each air gap forming portion (45, 49) comprises a free end (47, 51) and an end which is connected to the relevant portion of the core (3', 5'), the axis extending from the connected end to the free end, the cross-section of the air gap forming portions being substantially smaller near their free end than near their connected end.

4. A device as claimed in any one of the preceding Claims, characterized in that the air gap forming portions (9, 11) also comprise second surfaces (37, 39) which are oriented, in the vicinity of the fringes of the air gap (17), so that the normals (41, 43) to the parts of the second surfaces extending to both sides of the air gap enclose an angle of more than 0° relative to one another.

5. A device as claimed in Claim 4, characterized in that near the fringes of the air gap (17) the second surfaces (37, 39) are oriented so that the normals (41, 43) to the parts of the second surfaces extending to both sides of the air gap enclose an angle of at least 90° relative to one another.

6. A device as claimed in any one of the preceding Claims, characterized in that the width of the air gap (65) is greater near the fringes of the air gap than near the central portion thereof.

7. A device as claimed in any one of the preceding Claims, characterized in that there are provided adjusting means (55, 57, 59) for adjusting the distance between the facing first surfaces.

8. A device as claimed in Claim 7, characterized in that the adjusting means (55, 57, 59) include at least an adjusting screw.

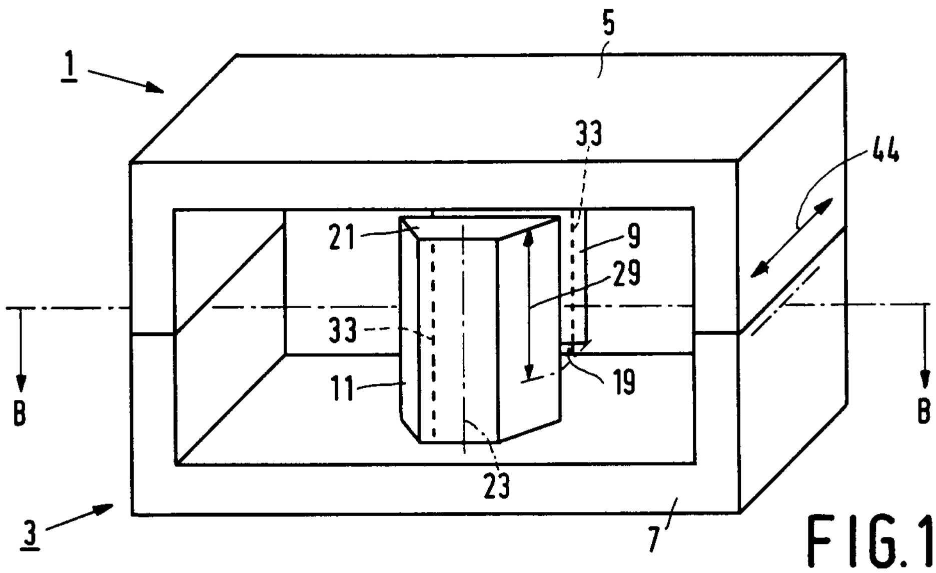


FIG.1A

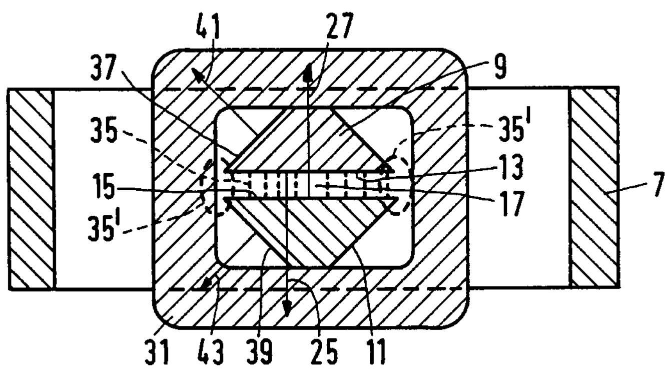


FIG.1B

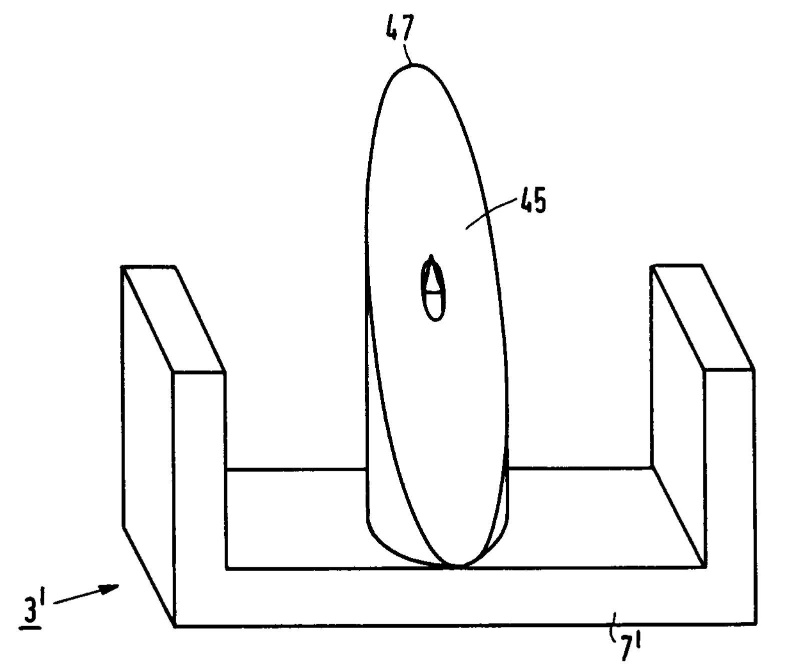


FIG.2A

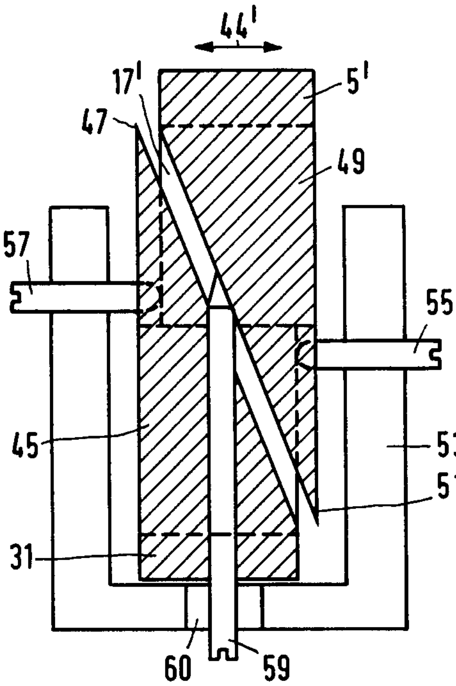


FIG.2B

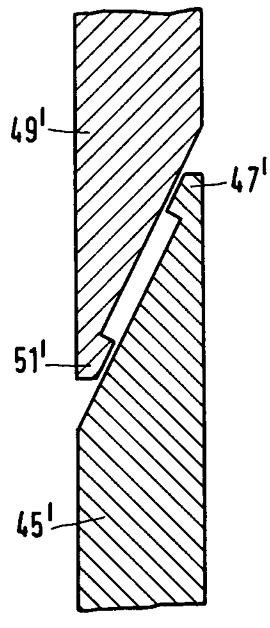


FIG.2C

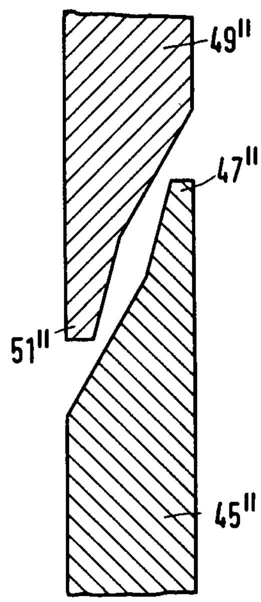


FIG.2D

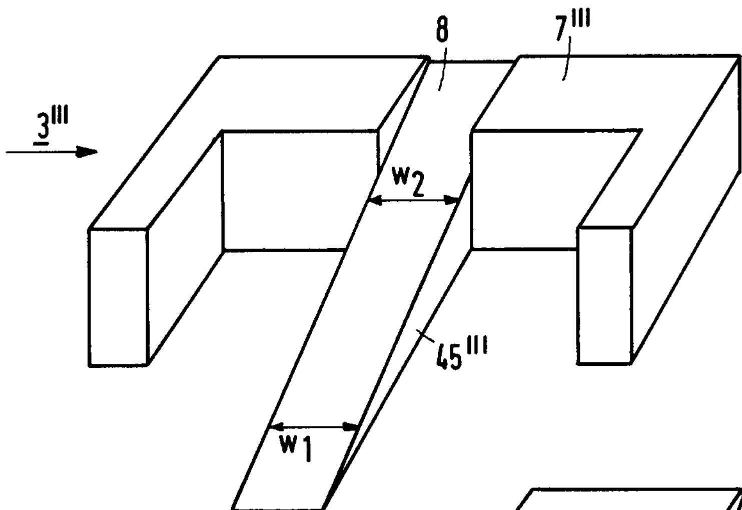


FIG.2E

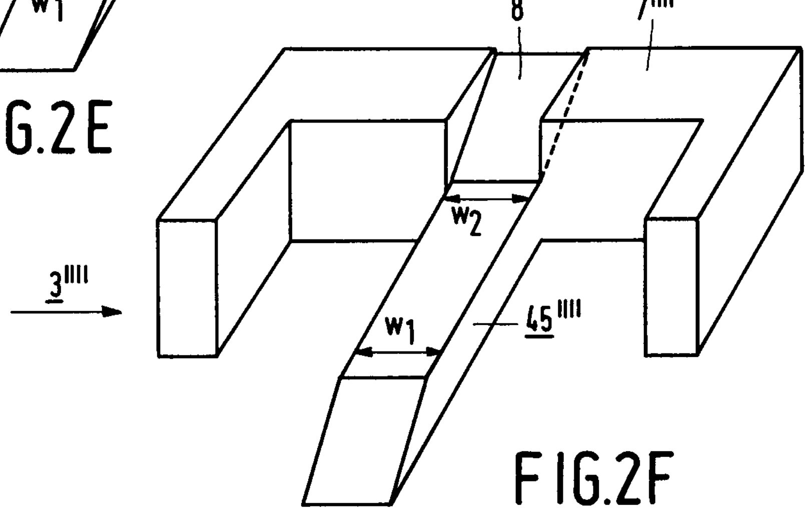


FIG.2F

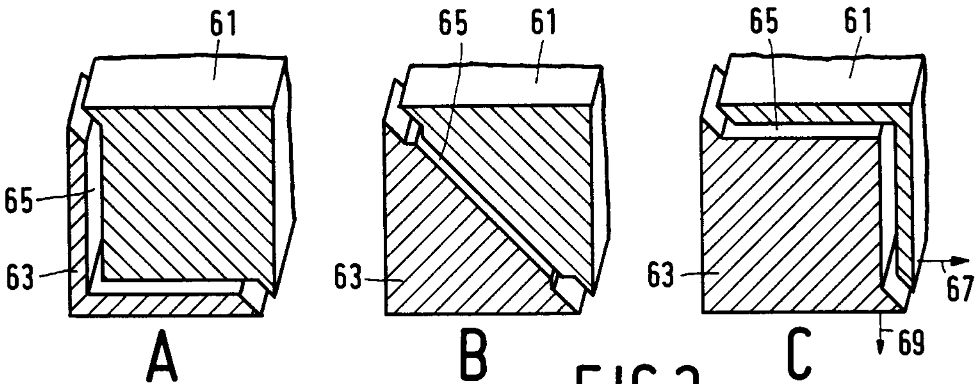


FIG.3

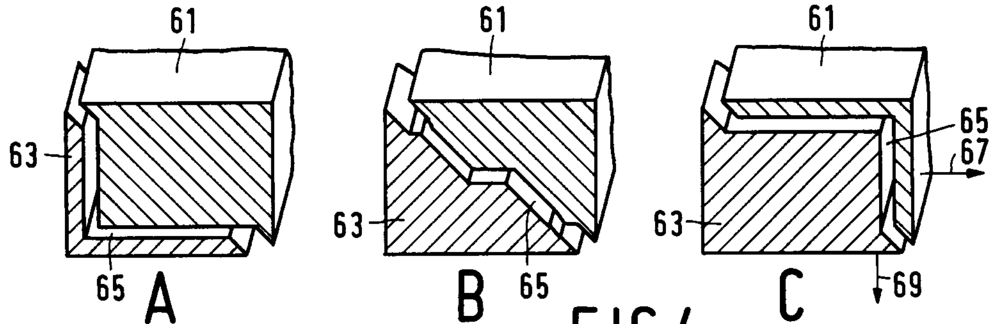


FIG.4

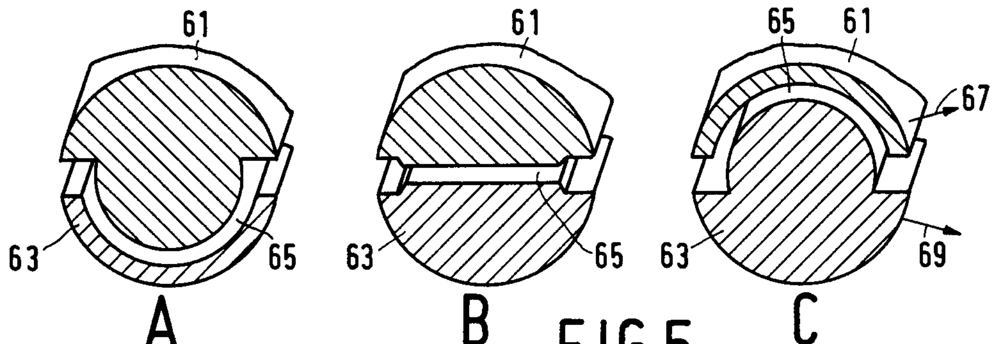


FIG.5

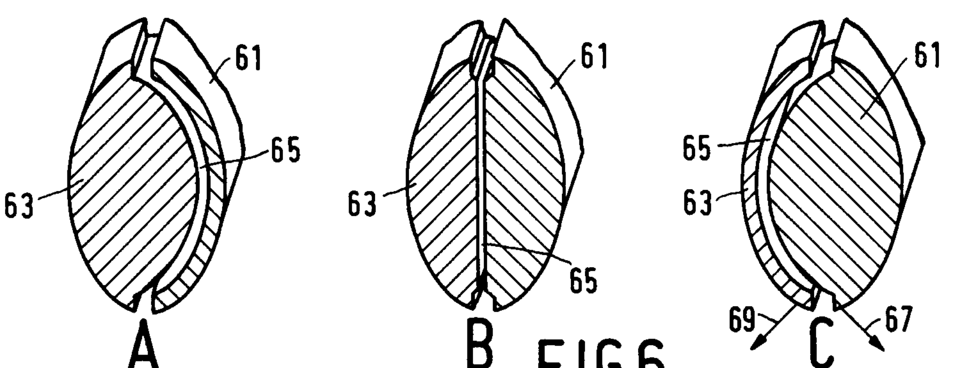


FIG.6

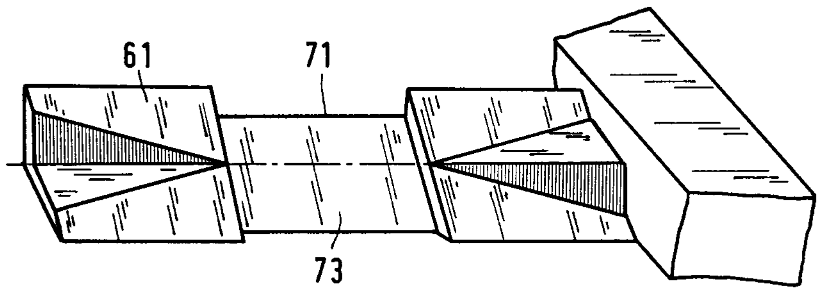


FIG. 7

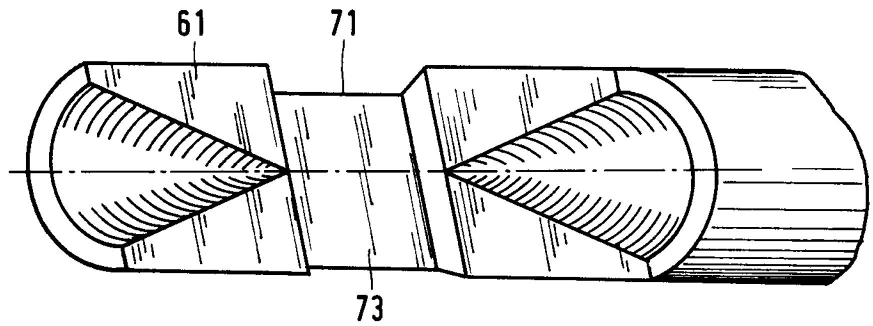


FIG.8

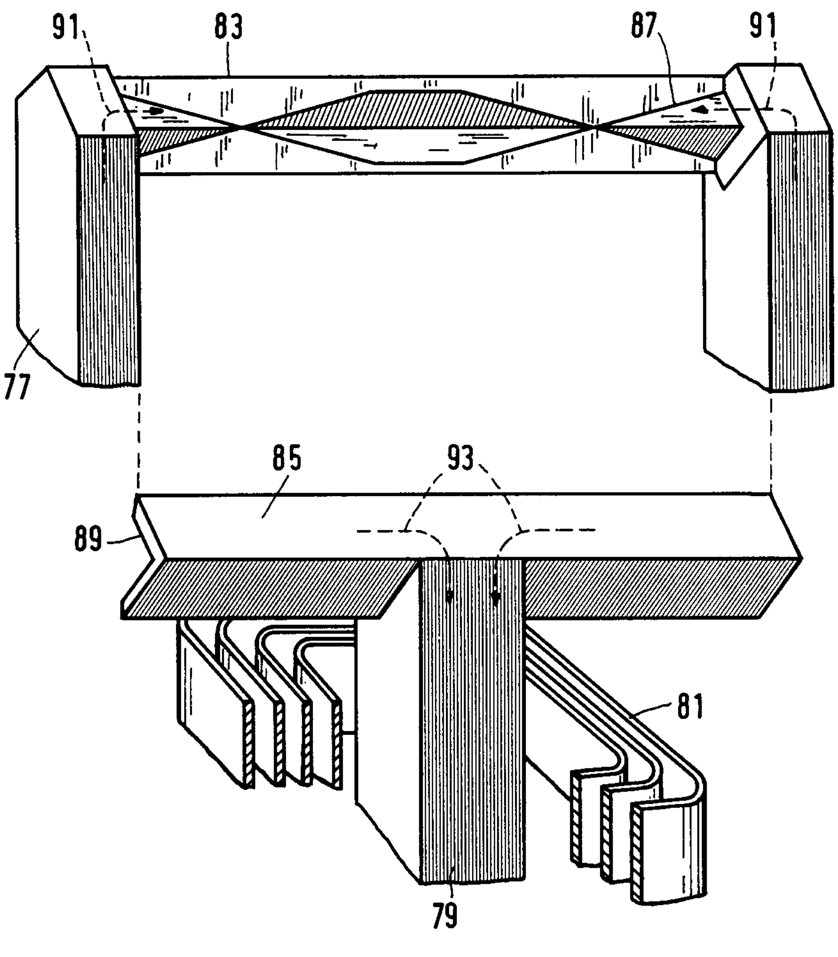
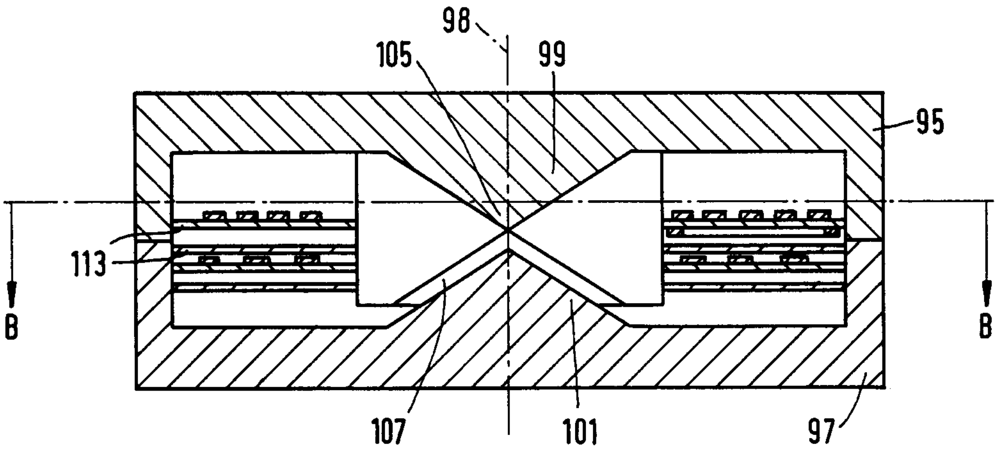


FIG.9



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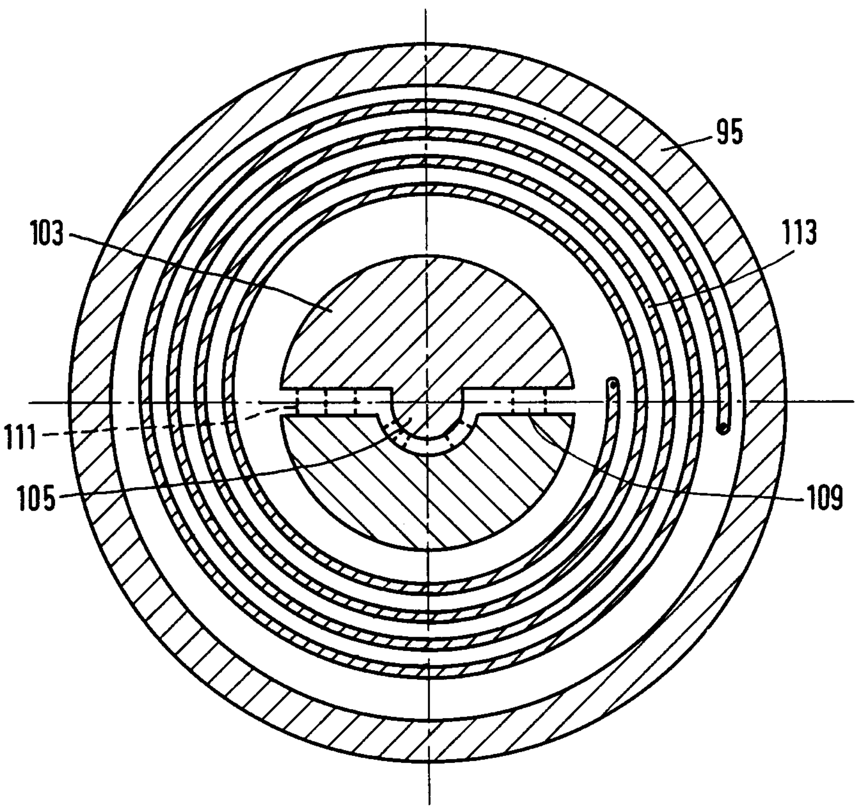

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European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 92 20 1628

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.5)
X	US-A-4 047 138 (GENERAL ELECTRIC COMPANY) * column 6, line 42 - column 7, line 6; figure 12 *	1	H01F3/14 H01F27/34
A		2	
A	CH-A-256 107 (FIDES) * figure 2 *	3	
A	US-A-1 991 400 (JOSEF LITTMANN) * figure 2 *	4,5,7,8	
D,A	EP-A-0 385 220 (TDK CORPORATION) * figures 15,17,18 *	6	
A	DE-A-3 402 278 (VOGT GMBH & CO)		
A	FR-A-894 733 (OPTA RADIO AKTIENGESELLSCHAFT)		

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

H01F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	23 SEPTEMBER 1992	VANHULLE R.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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P : intermediate document

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D : document cited in the application
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