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(54) ELECTROMAGNETIC INDUCTION DEVICE HAVING A FOIL WINDING

(57) The present disclosure relates to an electromagnetic induction device (1) comprising: a magnetic core (5) having a limb (7), a foil winding (9-3) wound around the limb (7), wherein the foil winding (9-3) has a first end portion (17) at a first axial end of the foil winding (9-3) and a second end portion (19) at a second axial end, opposite to the first axial end, of the foil winding (9-3), wherein each of the first end portion (17) and the second end portion (19) of the foil winding (9-3) is provided with cut-outs (21) along the circumference of the foil winding (9-3).

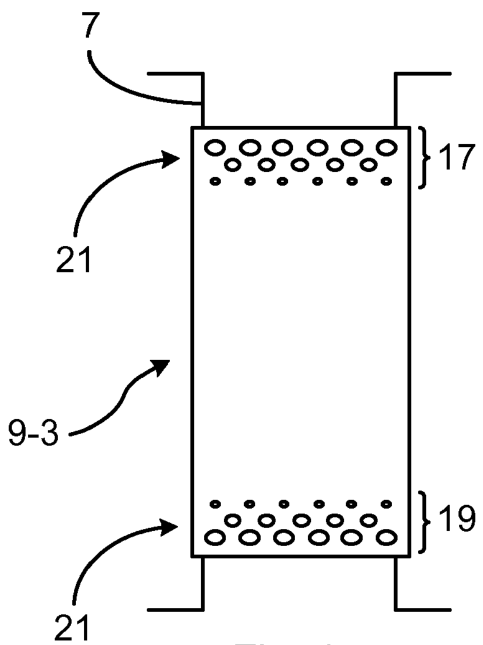

Fig. 4a

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Description

TECHNICAL FIELD

[0001] The present disclosure generally relates to electromagnetic induction devices such as transformers and reactors, and in particular to electromagnetic induction devices having foil windings.

BACKGROUND

[0002] Electromagnetic induction devices, such as transformers and reactors, are used in power systems for voltage level control. Hereto, a transformer is an electromagnetic induction device used to step up and step down voltage in electric power systems in order to generate, transmit and utilize electrical power in a cost effective manner. In a more generic sense a transformer has two main parts, a magnetic circuit, the core, made of e.g. laminated iron and an electrical circuit, windings.

[0003] Several types of windings may be used in electromagnetic induction devices. Foil windings such as aluminium or copper foil windings have unique advantages compared to wire windings due to their simplicity of manufacturing, their improved transient voltage distribution and superior short circuit fault withstand-ability. However, the usage of foil windings is limited to smaller rating power transformer due to uneven current distribution caused by fringing of the magnetic leakage flux at the ends of the foil winding. This results in high eddy losses and high temperature developments in the foil winding. The problem becomes worse with high leakage flux magnitude as the power rating increases.

[0004] GB990418 A discloses an electrically conducting shield structure for an electrical apparatus having a core and one or more foil windings to reduce current concentrations at the edges of the windings, caused by radial flux leakage, by establishing a magnetic field adjacent to the surface of each winding in opposition to the radial component of flux passing through the winding. Shields are arranged between the L.T. winding and core and surrounding the H.T. winding.

[0005] Although the design of GB990418 may reduce eddy current losses, it would however be desirable to further reduce eddy current losses in foil windings to be able to increase power ratings for electromagnetic induction devices utilising foil windings.

SUMMARY

[0006] An object of the present inventive concept is to provide electromagnetic induction devices which solve or at least mitigate the problems with existing solutions.

[0007] According to a first aspect of the present disclosure there is provided an electromagnetic induction device comprising a magnetic core having a limb, a foil winding wound around the limb, wherein the foil winding has a first end portion at a first axial end of the foil winding and a second end portion at a second axial end, opposite to the first axial end, of the foil winding, wherein each of the first end portion and the second end portion of the foil winding is provided with a plurality of cut-outs along the circumference of the foil winding.

[0008] An effect which may be obtainable thereby is that the current may be more evenly distributed in the foil winding. This may in particular be obtainable due to that the electrical resistance at the lateral ends of the foil winding is increased because of the cut-outs. The current distribution may thereby be more centred towards the middle section of the foil winding.

[0009] According to one embodiment the foil of each turn of the foil winding is provided with the cut-outs.

[0010] According to one embodiment the cut-outs are in the form of a plurality of through-openings.

[0011] According to one embodiment the cut-outs have a circular or elliptical shape.

[0012] According to one embodiment the first end portion and the second end portion each has a plurality of rows of the through-openings, wherein the rows extend longitudinally parallel with the circumferential direction of the foil winding, and wherein the dimension of the through-openings of the first end portion increases with each row towards the first axial end of the foil winding and wherein the dimension of the through-openings of the second end portion increases with each row towards the second axial end of the foil winding.

[0013] According to one embodiment the cut-outs are extending from the edge of the first axial end towards the centre of the foil winding, and wherein the cut-outs are extending from the edge of the second axial end towards the centre of the foil winding.

[0014] According to one embodiment the cut-outs are triangular-shaped, trapezoidal-shaped, or define a wave-like pattern in the circumferential direction of the foil winding.

[0015] According to one embodiment the first end portion and the second end portion each has a plurality of rows of cut-outs, wherein each row extends longitudinally along the circumferential direction of the foil winding, and wherein each pair of adjacent rows are overlapping axially and are displaced relative to each other in the circumferential direction of the foil winding.

[0016] According to a second aspect of the present disclosure there is provided an electromagnetic induction device comprising a magnetic core having a limb, a foil winding wound around the limb, a busbar, first connectors, second connectors and third connectors, wherein the foil winding is subdivided into a plurality of main sections that are electrically parallel connected, wherein the plurality of main sections include a central main section connected to the busbar by means of the first connectors, a first main end section connected to the busbar by means of the second connectors and a second main end section connected to the busbar by means of the third connectors, wherein the total impedance of the first main end part and the second connectors and the total impedance of the second main end part and the third connectors is larger than the total impedance of the central main section and the first connectors.

[0017] An effect which may be obtainable thereby is that the current may be more evenly distributed in the foil winding. This may in particular be obtainable because of the higher total impedance at the two end sections of the foil winding. This results in that the current distribution may be increased towards the central main section.

[0018] According to one embodiment the first main end section is subdivided into a plurality of first end sections, wherein the first end sections are electrically parallel connected.

[0019] According to one embodiment the second main end section is subdivided into a plurality of second end sections, wherein the second end sections are electrically parallel connected.

[0020] According to one embodiment the plurality of main sections include a central main section, a first main end section and a second main end section, wherein the central main section is made of copper foil, and the first main end section and the second main end section are made of aluminium foil.

[0021] The high resistance of the aluminium foil pushes down the current to the central copper foil. The eddy current loss at is thus reduced due to the high resistance of the aluminium foil. The length proportion of the aluminium and copper can be decided based on the resistivity ratio of aluminium and copper, i.e. ρ_{al}/ρ_{cu}, and the flux distribution to arrive at fairly uniform current distribution.

[0022] Generally, all terms used in the claims are to be interpreted according to their ordinary meaning in the technical field, unless explicitly defined otherwise herein. All references to "a/an/the element, apparatus, component, means, etc. are to be interpreted openly as referring to at least one instance of the element, apparatus, component, means, etc., unless explicitly stated otherwise.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] The specific embodiments of the inventive concept will now be described, by way of example, with reference to the accompanying drawings, in which:

Fig. 1 schematically shows the interior of an electromagnetic induction device;

Fig. 2a shows a side view of an example of a foil winding for the electromagnetic induction device in Fig. 1;

Fig. 2b shows the electrical circuit of the foil winding in Fig. 2a;

Fig. 3a shows another example of a foil winding for the electromagnetic induction device in Fig. 1;

Fig. 3b shows the electrical circuit of the foil winding in Fig. 3a;

Fig. 4a shows yet another example of a foil winding for the electromagnetic induction device in Fig. 1;

Fig. 4b shows an unwound portion of the foil winding in Fig. 4a;

Figs 5a and 5b show two more examples of a foil winding for the electromagnetic induction device in Fig. 1;

Fig. 6 shows a top view of a foil winding having cut-outs extending radially across all turns of the foil winding;

Fig. 7a shows yet another example of a foil winding for the electromagnetic induction device; and

Fig. 7b shows an unwound portion of the foil winding in Fig. 7a.

DETAILED DESCRIPTION

[0024] The inventive concept will now be described more fully hereinafter with reference to the accompanying drawings, in which exemplifying embodiments are shown. The inventive concept may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided by way of example so that this disclosure will be thorough and complete, and will fully convey the scope of the inventive concept to those skilled in the art. Like numbers refer to like elements throughout the description.

[0025] This disclosure covers two main aspects of an electromagnetic induction device which has a magnetic core with a limb, and a foil winding wound around the limb. Both aspects provide a more even current distribution along the axial direction of the foil winding.

[0026] The first aspect obtains this effect by means of a subdivision of the foil winding in the axial direction, thus obtaining a plurality of main sections. With subdivided is here mean that the main sections are physically separated from each other, and may be seen as a plurality of discs arranged along the longitudinal direction of the limb. The main sections are electrically parallel connected.

[0027] The second aspect obtains this effect by means of cut-outs provided in the foil winding, in particular in the foil constituting the foil winding, and which cut-outs are arranged along the tangential direction of the foil winding. The cut-outs extend through the foil. The cut-outs are arranged only along the two end portions of the foil winding. Due to the cut-outs the electrical resistance is increased in the two end portions of the foil winding, where eddy current losses are the greatest, and the current distribution in the foil winding may become more uniform.

[0028] Fig. 1 schematically shows a general electromagnetic induction device 1 comprising a tank or housing 3, a magnetic core 5 having a limb 7, and a foil winding 9 wound around the limb 7. A number of variations of the foil winding 9 will now be described with reference to Figs 2a to Fig. 7b.

[0029] Turning to Figs 2a and 2b, according to one example of the electromagnetic induction device 1, the foil winding 9 is subdivided into a plurality of main sections. In particular, the exemplified foil winding 9-1 is subdivided into a plurality of main sections 11 which include a first main end section 11b, a central main section 11a and a second main end section 11c. The main sections 11 are electrically parallel connected. The electromagnetic induction device 1 may further comprise a busbar B, first connectors C1, second connectors C2 and third connectors C3 schematically shown in the circuit diagram in Fig. 2b which shows the parallel connection of the main sections 11a, 11b and 11c.

[0030] The central main section 11a is connected to the busbar B by means of the first connectors C1, which is schematically shown in the circuit diagram in Fig. 2b. The first main end section 11b is connected to the busbar B by means of the second connectors C2. The second main end section 11c is connected to the busbar B by means of the third connectors C3. The first main end section 11b and the second connectors C2 have a total impedance Z1. The second main end section 11c and the third connectors C3 have a total impedance Z3. The central main section 11a and the first connectors C1 have a total impedance Z2. Each of the impedances Z1 and Z3 is larger than the impedance Z2. With the size of the impedances is here meant the magnitude of the impedances, i.e. their absolute value.

[0031] Even more uniform current distribution may potentially be obtained in the main sections 11 when the main sections 11 located at the two ends of the foil winding 9-1 are subdivided into additional sections. Fig. 3a shows an example of a foil winding 9-2 in which these main sections 11 are further subdivided.

[0032] The first main end section 11b may be subdivided into a plurality of first end sections 13a, 13b. The plurality of first end sections 13a, 13b are electrically parallel connected, as can be seen in Fig. 3b. The total impedance Z1 of the first end sections 13a, 13b and the second connectors C2 is larger than the total impedance Z2 of the central main section 11a and the first connector C1.

[0033] The second main end section 11c may be subdivided into a plurality of second end sections 15a, 15b. The plurality of second end sections 15a, 15b are electrically parallel connected. The total impedance Z3 of the second end sections 15a, 15b and the third connectors C3 is larger than the total impedance Z2 of the central main section 11a and the first connector C1.

[0034] The first main end section 11b and the second main end section 11c could according to one variation be further subdivided into more than two first end sections and second end sections, respectively.

[0035] According to one variation, the first main end section and the second main end section may be made of a foil that has higher resistivity than the central main section. To this end, the first main end section and the second main end section may for example be made of aluminium, and the central main section may be made of copper.

[0036] Turning now to the second aspect, the foil winding of all of these examples has a first end portion at a first axial end of the foil winding and a second end portion at a second axial end, opposite to the first axial end, of the foil winding. Each of the first end portion and the second end portion of the foil winding is provided with cut-outs. The cut-outs are distributed along the circumference of the foil winding. The cut-outs increase the impedance in the first end portion and in the second end portion of the foil winding, relative to the impedance of the central portion of the foil winding, which is not provided with cut-outs. The central portion of the foil winding hence has a continuous surface.

[0037] Fig. 4a shows an example of a foil winding 9-3 having a first end portion 17 at a first axial end of the foil winding 9-3 and a second end portion 19 at a second axial end, opposite to the first axial end, of the foil winding 9-3. Each of the first end portion 17 and the second end portion 19 of the foil winding 9-3 is provided with cut-outs 21, which according to the example in Fig. 4a are provided in the form of a plurality of through-holes extending radially through the foil of the foil winding 9-3. The through-openings are arranged in rows along the circumference of the foil winding 9-3. The through-openings may be arranged along the entire length unwound length of the foil winding 9-3 such that each turn of the foil winding 9-3 is provided with the through-openings.

[0038] Fig. 4b shows a portion of the foil winding in an unwound state, i.e. when it is a foil 10. The through-openings are arranged in a plurality of rows 23-27. The rows extend in the circumferential direction of the foil winding 9-3 parallel with each other.

[0039] According to one variation the dimension of the through-openings decreases for each row inwards towards the centre of the foil winding 9-3 in the axial direction thereof. The impedance of the foil winding 9-3 is hence gradually decreased in the axial direction inwards towards the centre of the foil winding 9-3. Alternatively, the dimension of the through-openings could increase for each row inwards towards the centre of the foil winding in the axial direction thereof, or the dimension may remain constant in each row, depending on the density of the rows.

[0040] The through-openings may for example be circular, elliptical or any other rounded shape. The through-openings could alternatively have angular or edgy shapes such as a rectangular or polygonal shape.

[0041] Fig. 5a shows another example of a foil winding. Foil winding 9-4 also has a first end portion 17 at a first axial end of the foil winding 9-4 and a second end portion 19 at a second axial end, opposite to the first axial end, of the foil winding 9-4. Each of the first end portion 17 and the second end portion 19 of the foil winding 9-4 is provided with cut-outs 21. According to this example, the cut-outs 21 are in the form of a plurality of cuts made in the edges of the foil winding 9-4, i.e. at the first axial end and at the second axial end of the foil winding 9-4. The cut-outs 21 are distributed along the circumference of the foil winding 9-4. The cut-outs 21 extend from the edge of the first axial end towards the centre of the foil winding 9-4, and from edge of the second axial end towards the centre of the foil winding 9-4. A close-up perspective view of the foil winding 9-4 is shown in the upper right corner of Fig. 5a.

[0042] The cut-outs 21 may for example be triangular-shaped, trapezoidal-shaped, or define a wave-like pattern in the circumferential direction of the foil winding. A foil winding 9-4' with a wave-like pattern created by the cut-outs 21 is shown in Fig. 5b. In the case of a wave-like pattern, the wave crests may be folded radially inwards towards the limb 7 so as to control the flux path of the leakage flux.

[0043] The cut-outs 21 may be made by cutting the entire foil when the foil has been wound around the limb 7 thus forming the foil winding 9-4 or when the foil is still in an unwound state. The cut-outs 21 may for example be made by means of laser cutting. This applies to any of the examples of foil windings having cut-outs presented herein.

[0044] Fig. 6 shows a top view of a foil winding, in particular a variation of the foil winding 9-4 in Fig. 5a. According to this example, the cut-outs 21 extend radially from the outermost foil turn to the innermost foil turn of the foil winding.

[0045] Figs 7a and 7b show yet another example of a foil winding. Foil winding 9-5 also has a first end portion 17 at a first axial end of the foil winding 9-5 and a second end portion 19 at a second axial end, opposite to the first axial end, of the foil winding 9-5. Each of the first end portion 17 and the second end portion 19 of the foil winding 9-5 is provided with cut-outs 21. According to this example, the cut-outs 21 extend longitudinally in the circumferential direction of the foil winding 9-5. The cut-outs 21 form a plurality of rows parallel to each other. Each pair of adjacent rows of cut-outs 21 are overlapping in the axial direction but are displaced relative to each other in the circumferential direction of the foil winding 9-5. In other words, each row of cut-outs 21 comprises a plurality of longitudinally extending cut-outs 21 arranged one after the other in the circumferential direction of the foil winding 9-5. The longitudinally extending cut-outs 21 of subsequent or adjacent rows are displaced relative to each other in the circumferential direction such that an alternating cut-out pattern is obtained. This design prevents or at least reduces the generation of eddy currents.

[0046] The electromagnetic induction devices presented herein may beneficially be medium voltage or high voltage electromagnetic induction devices. The magnetic core may comprise one or more limbs, with each limb being provided with a foil winding according to any of the examples provided herein. However, all of the foil windings of an electromagnetic induction device are preferably of the same type.

[0047] The inventive concept has mainly been described above with reference to a few examples. However, as is readily appreciated by a person skilled in the art, other embodiments than the ones disclosed above are equally possible within the scope of the inventive concept, as defined by the appended claims.

Claims

1. An electromagnetic induction device (1) comprising:

    a magnetic core (5) having a limb (7),
    a foil winding (9; 9-3; 9-4; 9-4'; 9-5) wound around the limb (7),
    wherein the foil winding (9; 9-3; 9-4; 9-4'; 9-5) has a first end portion (17) at a first axial end of the foil winding (9; 9-3; 9-4; 9-4'; 9-5) and a second end portion (19) at a second axial end, opposite to the first axial end, of the foil winding (9; 9-3; 9-4; 9-4'; 9-5),
    wherein each of the first end portion (17) and the second end portion (19) of the foil winding (9; 9-3; 9-4; 9-4'; 9-5) is provided with cut-outs (21) along the circumference of the foil winding (9; 9-3; 9-4; 9-4'; 9-5).

2. The electromagnetic induction device (1) as claimed in claim 1, wherein the foil of each turn of the foil winding is provided with the cut-outs (21).

3. The electromagnetic induction device (1) as claimed in claim 1 or 2, wherein the cut-outs (21) are in the form of a plurality of through-openings.

4. The electromagnetic induction device (1) as claimed in claim 3, wherein the cut-outs (21) have a circular or elliptical shape.

5. The electromagnetic induction device (1) as claimed in claim 3 or 4, wherein the first end portion (17) and the second end portion (19) each has a plurality of rows (23-27) of the through-openings, wherein the rows (23-27) extend longitudinally parallel with the circumferential direction of the foil winding (9-3), and wherein the dimension of the through-openings of the first end portion (17) increases with each row towards the first axial end of the foil winding (9-3) and wherein the dimension of the through-openings of the second end portion (19) increases with each row towards the second axial end of the foil winding (9-3).

6. The electromagnetic induction device (1) as claimed

in claim 1 or 2, wherein the cut-outs (21) are extending from the edge of the first axial end towards the centre of the foil winding (9-4), and wherein the cut-outs are extending from the edge of the second axial end towards the centre of the foil winding (9-4).

7. The electromagnetic induction device (1) as claimed in claim 6, wherein the cut-outs (21) are triangular-shaped, trapezoidal-shaped, or define a wave-like pattern in the circumferential direction of the foil winding (9-4').

8. The electromagnetic induction device (1) as claimed in claim 1 or 2, wherein the first end portion (17) and the second end portion (19) each has a plurality of rows of cut-outs (21), wherein each row extends longitudinally along the circumferential direction of the foil winding (9-5), and wherein each pair of adjacent rows are overlapping axially and are displaced relative to each other in the circumferential direction of the foil winding (9-5).

9. An electromagnetic induction device (1) comprising:

a magnetic core (5) having a limb (7),
a foil winding (9; 9-1; 9-2) wound around the limb (7),
a busbar (B),
first connectors (C1), second connectors (C2) and third connectors (C3),
wherein the foil winding (9; 9-1; 9-2) is subdivided into a plurality of main sections (11) that are electrically parallel connected, wherein the plurality of main sections (11) include a central main section (11a) connected to the busbar (B) by means of the first connectors (C1), a first main end section (11b) connected to the busbar (B) by means of the second connectors (C2) and a second main end section (11c) connected to the busbar (B) by means of the third connectors (C3), wherein the total impedance of the first main end part (11b) and the second connectors (C2) and the total impedance of the second main end part (11c) and the third connectors (C3) is larger than the total impedance of the central main section (11a) and the first connectors (C1).

10. The electromagnetic induction device (1) as claimed in claim 9, wherein the first main end section (11b) is subdivided into a plurality of first end sections (13a, 13b), wherein the first end sections (13a, 13b) are electrically parallel connected.

11. The electromagnetic induction device (1) as claimed in claim 9 or 10,wherein the second main end section (11c) is subdivided into a plurality of second end sections (15a, 15b), wherein the second end sections (15a, 15b) are electrically parallel connected.

12. The electromagnetic induction device (1) as claimed in any of claims 9-11, wherein the plurality of main sections (11) include a central main section (11a), a first main end section (11b) and a second main end section (11c), wherein the central main section (11a) is made of copper foil, and the first main end section (11b) and the second main end section (11c) are made of aluminium foil.

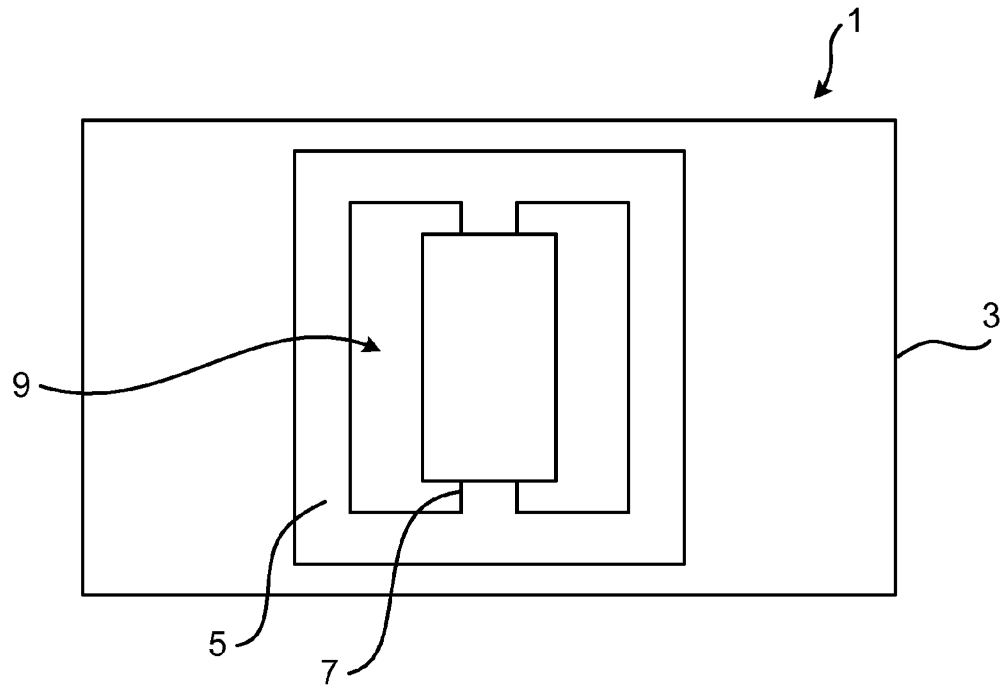

Fig. 1

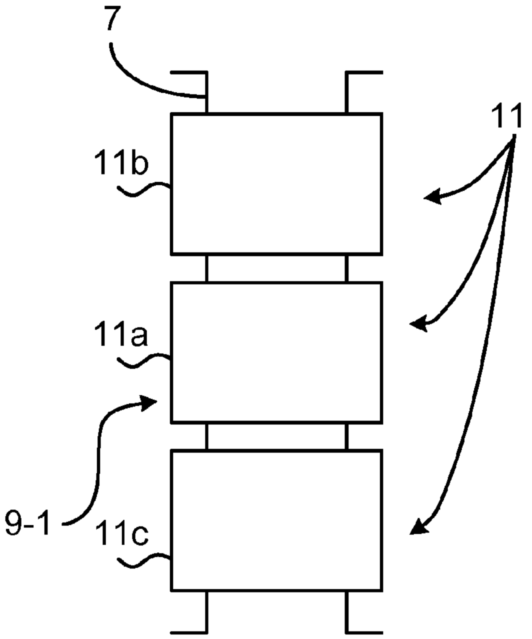

Fig. 2a

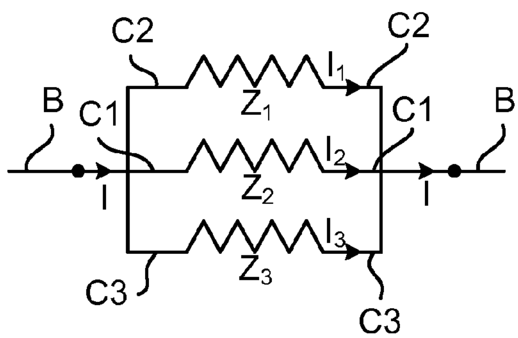

Fig. 2b

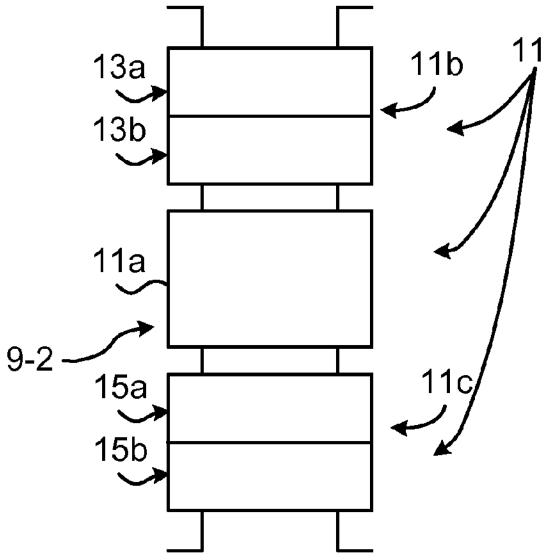

Fig. 3a

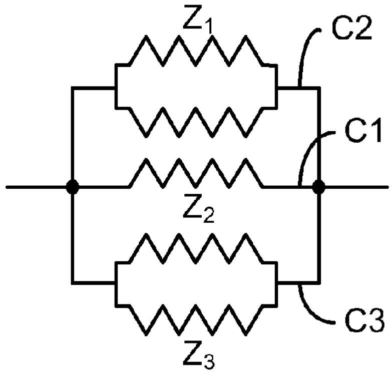

Fig. 3b

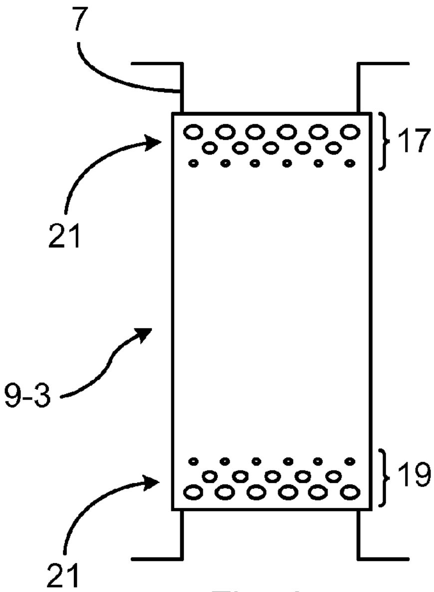

Fig. 4a

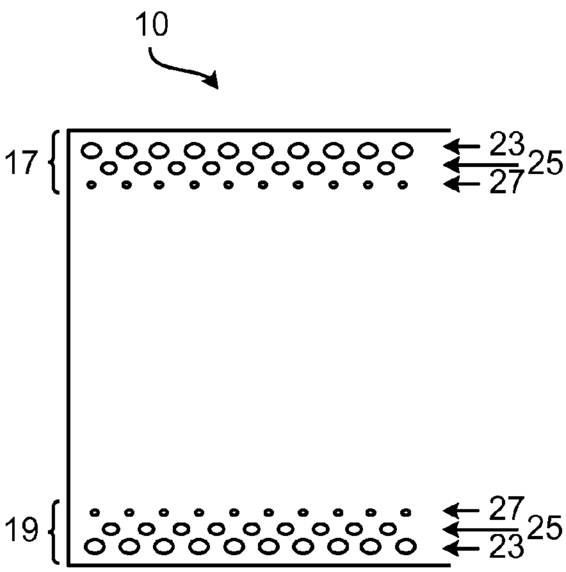

Fig. 4b

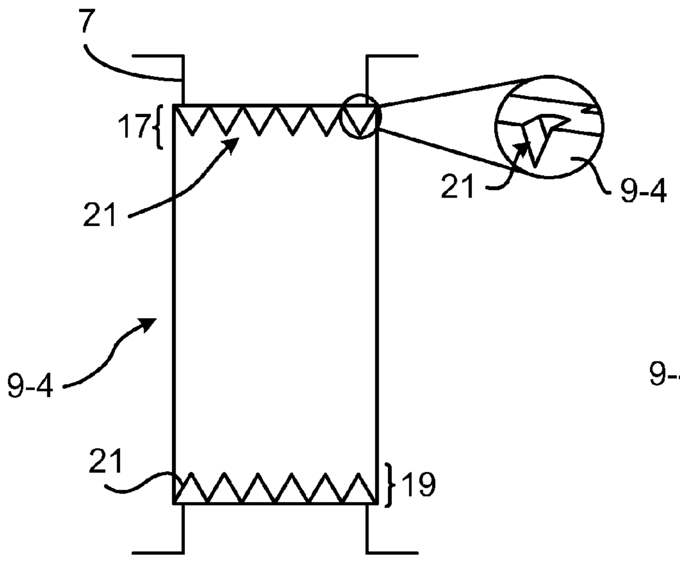

Fig. 5a

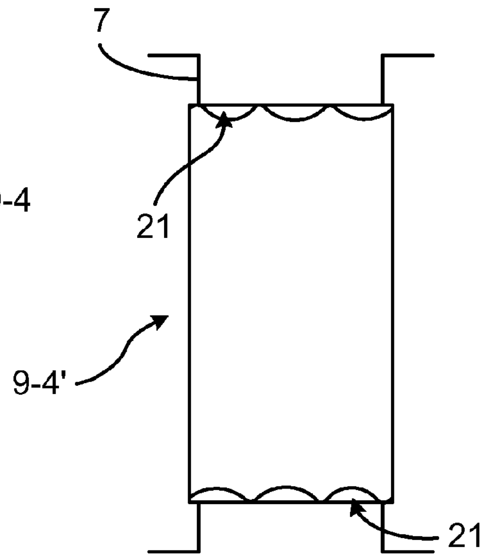

Fig. 5b

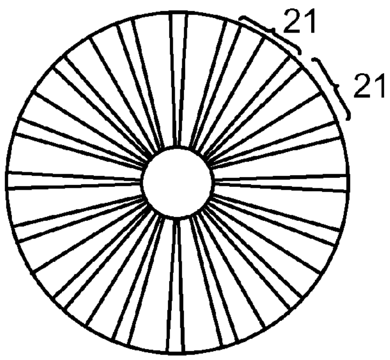

Fig. 6

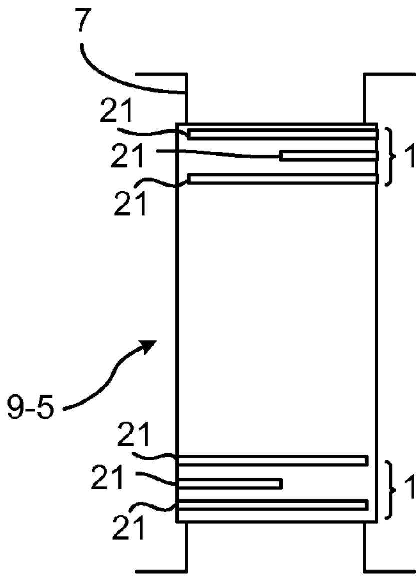

Fig. 7a

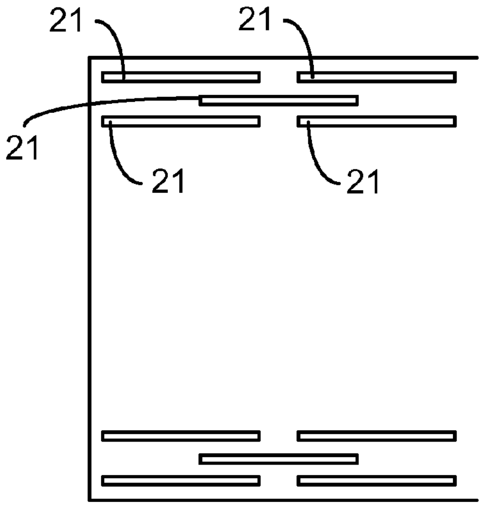

Fig. 7b

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 15 18 0387

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X A	WO 2005/096330 A1 (DARTMOUTH COLLEGE [US]; SULLIVAN CHARLES ROGER [US]; POLLOCK JENNIFER) 13 October 2005 (2005-10-13) * figures 14,15 * * page 8, line 27 - page 9, line 3 *	1-4 5-8	INV. H01F27/28 H01F38/14 H01F27/38 H01F27/34 H01F27/40
X	US 3 142 029 A (KEEN JR WILLIAM A ET AL) 21 July 1964 (1964-07-21) * figures 3-5 *	1,3,4	
X A	US 3 996 444 A (BENTELER HELMUT ET AL) 7 December 1976 (1976-12-07) * figure 3 * * column 4, line 55 - column 5, line 35 *	9,12 10,11	
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The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
Munich	28 January 2016	Rouzier, Brice

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