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(54) **Flat band winding for an inductor core**

(57) The invention provides a flat band winding for an inductor core comprising at least one insulated conductive flat band having a first linear region, a second linear region , and a third linear region, wherein the third linear region is substantially orthogonally connected to said first linear region and to said second linear region such that said first linear region and said second linear region are displaced by a distance and run in parallel or anti-parallel, and wherein said first linear region and said second linear region are wound in opposite directions around the inductor core and around said third region.

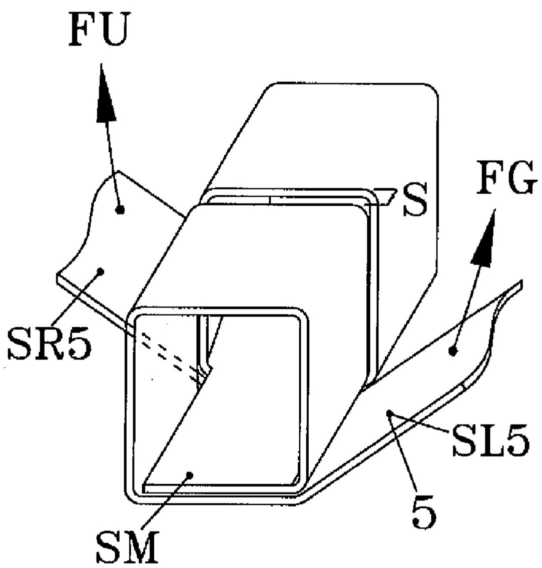

Fig. 5c

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Description

[0001] This invention relates to a flat band winding for an inductor core

State of the Art

[0002] Flat band windings for inductor cores are e.g. known from DE 100 40 415 C1 and WO 2007/136288 A1.

[0003] US 7,573,362 B2 discloses a high-current, multiple air gap, conduction-cooled, stacked lamination inductor. Particularly, the magnetic core section of this known inductor includes substantially rectangular profiled magnetic laminations arranged in a stack.

[0004] Generally, in order to reduce the size of power electronics devices, converters are designed which use working frequencies that for small power converters up to 10 V have risen into the MHz range. The research of middle power converters up to 200V and high power converters up to 500V is seeking to reach frequencies in the range of 300 kHz up to 1 MHz.

[0005] In such converters, the inductor presents an important part regarding the losses and the size. Particularly, the inductor's size should be minimal, and if possible, the inductor shape should be square and the inductor should have the lowest possible AC/DC resistance ratio at the desired working frequency. In the existing inductors which are used in the high frequency area the skin effect, proximity effect and fringing effect are the reason for comparatively high losses and correspondingly required big size.

[0006] In order to obtain the smallest possible inductor with a low DC resistance the majority of the known switching converter inductors is wound with a circular or squared wire on different shape ferrite cores with one or two air gaps. Better results are reached with inductors having their winding enclosed in powder material which due to low permeability replaces the air gap.

[0007] Relatively best results are achieved by the prior art inductor shown in Fig. 14, where TC denotes a toroidal ferrite core with an air gap AG and having strand wire SW wound around the core TC. The prior art inductors shown in Fig. 14 show a favourable AC/DC current resistance ratio, however, their field radiation is high, their size is big, and their shape is inconvenient to be fixed on a circuit board.

[0008] High-frequency current in circular or square-shape free wires is conducted only in the wire surface area which is called skin effect. That effects that the known inductors wound with such wires to have very low resistance and also high inductivity vary their resistance with increasing frequency very dramatically. Therefore, the high-frequency losses make the known inductors only useful for low alternating current frequencies. The air gap also contributes to increase the high-frequency losses. The magnetic flux exits the core in the area of the air gap and enters the winding causing heating of the winding. Even the replacement of a single air gap by plural air gaps does not reduce the effect of this heating phenomenon very much at high frequencies. Although the effect can be completely eliminated by using a composite ferrite material as core material, the permeability of a corresponding inductor depends very much on the magnetic density. Moreover, the composite ferrite material has a much lower saturation level than the sintered ferrite material. This effects that the inductivity of such composite ferrite material inductors varies drastically with current changes.

Disclosure of the Invention

[0009] The invention provides a flat band winding as defined in independent claim 1 and 2, respectively.

[0010] Preferred embodiments are listed in the respective dependent claims.

Advantages of the Invention

[0011] The invention is well suited for high ripple current applications at high frequencies.

Brief Description of the Drawings

[0012] In the following embodiments of the invention will be described with reference to the drawings, wherein:

Fig. 1	shows a cross-section of a multi gap inductor core;
Fig. 2	shows a cross-section of a multi gap inductor core of Fig 1 in order to explain a corresponding manufacturing method thereof;
Fig. 3, 4	are perspective views in order to explain the step of separating individual multi gap inductor cores from the hardened stack manufactured as explained in Fig. 2;
Fig. 5a	is a plain view of a first embodiment of an insulated conductive flat band used as a winding in connection with the multi gap inductor core;
Fig. 5b,c	are perspective views of the insulated conductive flat band shown in Fig. 5a in order to illustrate a first winding procedure;
Fig. 6	is a perspective view of the first embodiment of insulated conductive flat band used as a winding in connection with the multi gap inductor core after the first winding procedure is finished;
Fig. 7	shows a cross-section of a multi gap inductor having the winding type of Fig. 6;

Fig. 8 shows a cross-section of a multi gap inductor having a strand wire winding type;

Fig. 9a is a plain view of a second embodiment of an insulated conductive flat band used as a winding in connection with the multi gap inductor core;

Fig. 9b,c are perspective views of multiple parallel windings of the insulated conductive flat band shown in Fig. 9a in order to illustrate a second winding procedure;

Fig. 10 is a perspective view of the second embodiment of multiple parallel windings of insulated conductive flat band used as a winding in connection with the multi gap inductor core after the second second winding procedure is finished;

Fig. 11a,b are plain views of the first example of insulated conductive flat bands in form of a first and second specially stacked flat bands used as a winding in connection with the multi gap inductor core;

Fig. 12 shows a partial cross-section of another multi gap inductor core;

Fig. 13 shows a schematic view of a transformer including a multi gap inductor core; and

Fig. 14 shows an example of a inductor core according to the prior art.

Embodiments of the Invention

[0013] Throughout the figures, the same reference signs denote same or equivalent parts.

[0014] Fig. 1 shows a cross-section of a multi gap inductor core.

[0015] In Fig. 1 reference sign 1 denotes a multi gap inductor core according an embodiment of the present invention. The core 1 includes a plurality of seven magnetic lamination sheets 2a-2g made of a ferrite material with lowest possible losses for the desired frequency range. Reference sign HA denotes a length axis of the core 1, i.e. along the staggering direction of the laminations 2a-2g.

[0016] If, for example, the 1 MHz frequency range is desired, an appropriate ferrite material would be Ferrouxcube 3F45. By presently known cutting methods a minimum lamination thickness d1 of about 0,2 mm can be reached, allowing the permeability to be low and to have a good gap distribution.

[0017] Between corresponding pairs of adjacent magnetic laminations there is provided a corresponding hardened non magnetic and non conducting glue layer 3a-3f. Each glue layer 3a-3f includes a spacer means 4 in form of spherical particles made of carbon, socalled glassy carbon spherical powder, which define a gap G having a predetermined thickness d2 between each corresponding pair of magnetic lamination sheets 2a-2g. Since a narrow size diameter distribution can be obtained by filtering such carbon material, the diameter d3 of the carbon particles 4 substantially equals the predetermined thickness d2 of the gap G. In other words, there is a monolayer of carbon particles included in the hardened glue layers 3a-3f acting as said mechnical spacer means. Only a few carbon particles per mm^2 are sufficient to ensure a very homogeneous gap G. The carbon particles are also non magnetic and badly conductive and solid even at the temperature which develops in the glue during hardening step, e.g. 180°C. Specifically, the spacer particles do not influence the magnetic flux and do not produce any disturbing heating effect.

[0018] The core 1 according to the embodiment of Fig. 1 allows the production of an inductor having excellent performance and comparatively low losses in the desired frequency range, here 1 MHz. The total gap of the core of Fig. 1 is the sum of all gaps G from where the magnetic field is dissipated only in a very small area causing no additional losses in the winding. The winding therefore can take the space very close to the core 1.

[0019] Fig. 2 shows a cross-section of a multi gap inductor core of Fig. 1 in order to explain a corresponding manufacturing method thereof.

[0020] As depicted in Fig. 2 the desired number of magnetic lamination sheets 2a-2g is stacked on top of each other, wherein between the pairs of adjacent magnetic lamination sheets the glue layers 3a-3f are dispensed by appropriate dispensing means. The glue layer is a premix of glue and the spherical carbon particles 4.

[0021] In order to obtain the favourable concentration of some particles per mm^2 the concentration of the particles in the glue is typically between 0,1 and 3 %, preferably 1 %. If the volume concentration is too high there would be the risk that the particles stick together making the gap thickness d2 inhomogeneous. On the other hand, if the volume concentration of the particles is too low, the particles could be not evenly distributed over the area between adjacent laminations and therefore also make the thickness d2 inhomogeneous. Despite of these lower and upper limitations which can normally be found very easily by experiments, the range of applicable concentrations still stays broad.

[0022] When the stack with the desired number of laminations 2a-2g and the intervening glue/spacer layers 3a-3f are completed, a pressure P is applied on the stack such that the spherical carbon particles 4 can exactly match and define the gap G with the predetermined thickness d2 according to their own diameters d3. Depending on the type of glue, e.g. epoxy glue, the hardening can then be performed at room temperature or elevated temperatures, while the application of pressure P is continued until the stack is completely hardened.

[0023] Fig. 3, 4 are perspective views in order to explain the step of separating individual multi gap inductor cores from the hardened stack manufactured as explained in Fig. 2.

[0024] It should be mentioned that especially for small core diameters, the dimensions of the stack orthogonal to the length axis HA do not correspond to the dimensions of the finished core.

[0025] In the example of Fig. 2, the dimensions of the hardened stack 100 are 80 mm width, 50 mm depth, and 25 mm length.

[0026] In order to provide individual cores 1', the hardened stack 100 is cut by means of a wafer saw (i.e. diamond saw) or wire saw into rows 100a and then into the cores 1', where the laminations are labelled 2a'-2m' and the glue/spacer layers 3a'-3l'.

[0027] By using an appropriate sawing process arbitrary core shapes may be obtained, for example, circular shapes as shown in Fig. 4 for the core 1" including laminations 2a"-2n" and glue/spacer layers 3a"-31".

[0028] This manufacturing method allows an accuracy of typically 5% of the inductance value and very small gaps. In a further example, 1,3 mm of gap were distributed among 65 ferrite sheets. The tolerance accuracy can be improved by sorting out and assembling together two or more partial core stacks in order to provide air gaps with desired small tolerances.

[0029] Fig. 5a is a plain view of a first embodiment of an insulated conductive flat band (also sometimes denoted in the art as strip) used as a winding in connection with the multi gap inductor core; and Fig. 5b,c are perspective views of the insulated conductive flat band shown in Fig. 5a in order to illustrate a first winding procedure.

[0030] The insulated conductive flat band 5 shown in Fig. 5a-c is made of insulated conductive material such as copper or aluminum and includes a first linear region SR, a second linear region SL and a third linear region SM. The width b1 of the first linear region SR is equal to the width b1 of the second linear region SL, and the width b2 of the third linear region SM is 2 x b1 + S, where S is a given distance. This means that the first and second linear regions SR, SL are displaced by the distance S.

[0031] Moreover, the first and second linear regions SR, SL are orthogonally connected to the third linear region SM and run in anti-parallel directions as may be clearly obtained from Fig. 5a. Virtual segments SR1-SR5 of the first linear region SR having a length l are denoted in order to show the folding lines when winding the insulated conductive flat band 5 around a core according to an embodiment of the present invention occurs. Analogously SL1-SL5 denote virtual segments of the second linear region SL having all the length l which is a little bit larger than the diameter of the core to be used.

[0032] As may be obtained from Fig. 5b and 5c the first linear region SR and the second linear region SL are wound in opposite directions FU (clockwise) and FG (counter-clockwise) around the third linear region SM in order to form the winding around the core.

[0033] Fig. 6 is a perspective view of the first embodiment of insulated conductive flat band used as a winding in connection with the multi gap inductor core after the first winding procedure is finished.

[0034] A finished winding 5' made of an insulated conductive flat band as shown in Figs. 5a-c is shown in Fig. 6. As depicted, it is preferred that the ends E1, E2 of the finished winding 5' are orthogonal to the length axis HA of the core to be inserted into the finished winding 5'.

[0035] Fig. 7 shows a cross-section of a multi gap inductor having the winding type of Fig. 6.

[0036] The finished inductor of Fig. 7 includes a multi gap core 1''' having 20 laminations with intervening glue/spacer layers as explained in connection with Figs. 1 and 2 and having a surrounding winding 5" in analogy to the winding 5' described with reference to Fig. 6, however, having a larger number of winding turns.

[0037] As may be clearly obtained from Fig. 7, the gap β between the core 1''' and the winding 5" can be made very small. The section A of Fig. 7 is shown in enlarged form on the righthand side of Fig. 7 and also shows the space s which corresponds to the distance S between the first and second linear regions SR, SL.

[0038] Reference sign V finally denotes a magnetic shielding which surrounds the inductor according to this embodiment and closes the magnetic field of the coil.

[0039] Fig. 8 shows a cross-section of a multi gap inductor having a strand wire winding type.

[0040] In Fig. 8 the laminated core 1''' is surrounded by a strand wire 50. All further details are the same as described above with respect to Fig. 7.

[0041] Fig. 9a is a plain view of a second embodiment of an insulated conductive flat band used as a winding in connection with the multi gap inductor core; and Fig. 9b,c are perspective views of multiple parallel windings of the insulated conductive flat band shown in Fig. 9a in order to illustrate a second winding procedure.

[0042] The insulated conductive flat band 25 shown in Fig. 9a includes first linear region SU, a second linear region SO and a third linear region SM'. As in the example of Fig. 5a, the third linear region SM' is substantially orthogonally connected to the first linear region SU and to said second linear region SO, wherein the first linear region SU and the second linear region SO are displaced by a distance S, however, in contrast to the example in Fig. 5a run in parallel. The distance S arises from the difference of the width b2 of the third linear region SM' and the sum of the width b1 of the first and second linear regions SU, SO.

[0043] In these examples virtual segments SU1-SU5 of the first linear region SU and virtual segments SO1-SO5 of the second linear region SO are depicted in order to clarify the folding lines when the insulated conductive flat band 25 of Fig. 9a is wound to form a winding around a core.

[0044] As shown in Fig. 9b a plurality of insulated conductive flat bands of the 25, 25', 25", 25''' of the type shown in Fig. 9a is isolatedly stacked on top of each other. The isolation can be achieved by using a foil, e.g. Kapton foil a resin or a native or artificial oxide on the surface of the insulated conductive flat bands 25, 25', 25", 25"'.

[0045] As may be obtained from Fig. 9c, the stack of insulated conductive flat bands 25, 25', 25", 25'" shown in Fig. 9b is then wound in opposite directions FU (clockwise) and FG (anticlockwise) around the third linear regions of the insulated conductive flat bands 25, 25', 25", 25'" in order to form the winding around a core.

[0046] Fig. 10 is a perspective view of the second embodiment of multiple parallel windings of insulated conductive flat band used as a winding in connection with the multi gap inductor core after the second winding procedure is finished.

[0047] The final winding shape is shown in Fig. 10, wherein the ends E1', E2' are also bend orthogonal to the length axis HA of the core in accordance with the embodiments of the present invention to be inserted into the wound winding.

[0048] In the embodiment shown in Fig. 10 the outer flat band 25 on one side becomes the inner flat band on the other side when wound in opposite directions FU, FG. This contributes to counteract the proximity effect which otherwise would tend to shift the high-frequency current in the outermost flat band area. In particular, the stack sequence change equalizes the induced voltage along the bands in order to avoid a current along the bands.

[0049] Fig. 11a,b are plain views of the first embodiment of insulated conductive flat band in form of a first and second specially stacked flat bands used as a winding in connection with the multi gap inductor core.

[0050] In the embodiment shown in Fig. 11 a winding around a core in accordance with the embodiments described is made of two insulated conductive flat bands 5a, 5b of the type shown in Fig. 5a which are specially stacked on top of each other in an isolated manner.

[0051] In the insulated conductive flat bands 5a, 5b shown in Fig. 11a SRa, SRb denote the corresponding first linear region of the first and second flat band 5a, 5b and SLa, SLb denote the corresponding second linear region of the flat bands 5a, 5b, whereas SMa and SMb correspond to a respective third linear region connecting the first and second linear regions of the flat bands 5a, 5b.

[0052] Before being wound the insulated conductive flat bands 5a, 5b shown in Fig. 11a are stacked isolatedly on each other such that there is a crossover such that on one side the first linear region SRa of the first insulated conductive flat band 5a lies above the first linear region SRb of the second insulated conductive flat band 5b, however, on the other side the second linear region SLa of the first insulated conductive flat band 5a lies below the second linear region SLb of the second insulated conductive flat band 5b. In the crossover region there is a small lateral gap S' x S between the insulated conductive flat bands 5a, 5b.

[0053] When winding the stacked arrangement of the first and second insulated conductive flat bands 5a, 5b shown in Fig. 11b it also becomes possible like in the embodiment shown in Fig. 10 that the outer flat band on one side becomes the inner flat band on the other side when wound in opposite directions FU, FG. This contributes to counteract the proximity effect which otherwise would tend to shift the high-frequency current in the outermost flat band area.

[0054] Fig. 12 shows a partial cross-section of another multi gap inductor core.

[0055] In this embodiment, spacer means 4' includes a photolithgraphically structured Al_2O_3 layer having a plurality of cube shape bumps 4' between which the hardended fixing layers 3f etc. are provided. Here the fixing layer 3f is not made of glue but of adhesive wax.

[0056] Fig. 13 shows a schematic view of a transformer including a multi gap inductor core.

[0057] In Fig. 13 reference sign 1 denotes a multi gap inductor core according to the embodiment of the present invention shown in Fig. 1, and W1, W2 denote a primary and secondary winding wound around the core so as to form a transformer T.

[0058] Although the present invention has been described with reference to particularly embodiments, various modifications can be performed without departing from the scope of the present invention as defined in the independent claims.

[0059] In particular, the spacer means is not restricted to the specified carbon particles or Al_2O_3 bumps, but other materials, e.g. sand particles or quartz particles, or spacer foils or meshes may be used as well. Also the shape of the particles or bumps is not restricted to the circular or square cube shape, but can have various other shapes, such as polyedral shape, etc., however, it still is important that the diameter distribution is narrow enough to achieve the desired homogeneity of the gap thickness between the individual laminations. Moreover, various materials can be used for the laminations, the fixing material and the windings, and the invention is not restricted to the materials and dimensions mentioned hereinbefore. E.g. further examples of the fixing material are Teflon, resist and grease which can be sufficiently hardenend.

Claims

1. Flat band winding for an inductor core, comprising:

at least one insulated conductive flat band (5; 5'; 5"; 5a, 5b) having a first linear region (SR; SRa; SRb), a second linear region (SL; SLa; SLb), and a third linear region (SM; SMa; SMb), wherein the third linear region (SM; SMa; SMb) is substantially orthogonally connected to said first linear region(SR; SRa; SRb) and to said second linear region (SL; SLa; SLb) such that said first linear region(SR; SRa; SRb) and said second linear region (SL; SLa; SLb) are displaced by a distance (S) and run in anti-parallel, and wherein said first linear region(SR; SRa; SRb) and said second linear region (SL; SLa; SLb) are wound in opposite directions (FU, FG) around the inductor core (1; 1'; 1"; 1"') and around said third region (SM; SMa; SMb).

2. Flat band winding for an inductor core, comprising:

at least one insulated conductive flat band (25, 25', 25", 25"') having a first linear region (SU), a second linear region (SO), and a third linear region (SM'), wherein the third linear region (SM') is substantially orthogonally connected to said first linear region (SU) and to said second linear region (SO) such that said first linear region (SU) and said second linear region (SO) are displaced by a distance (S) and run in parallel, and wherein said first linear region (SU) and said second linear region (SO) are wound in opposite directions (FU, FG) around the inductor core (1; 1 ; 1"; 1"') and around said third region (SM').

3. Flat band winding of claim 1 or 2, wherein a width b1 of the first linear region (SR; SU) is equal to a width b1 of the second linear region (SL; SO), and wherein a width b2 of the third linear region (SM; SM') is 2 x b1 + S, where S is the given distance.

4. Flat band winding of claim 1 or 2, wherein the first linear region (SR; SU), the second linear region (SL; SO) and the third linear region (SM; SM') are rectangular.

5. Flat band winding of claim 1 or 2, wherein a plurality insulated conductive flat bands (5a, 5b; 25, 25', 25", 25"') is isolatedly stacked on top of each other.

6. Flat band winding of claim 1, wherein a first and second insulated conductive flat bands (5a, 5b) are isolatedly stacked on top of each other such that there is a crossover such that on one side the first linear region (Sra) of the first insulated conductive flat band (5a) lies above the first linear region (SRb) of the second insulated conductive flat band (5b), and on the other side the second linear region (SLa) of the first insulated conductive flat band 5a lies below the second linear region (SLb) of the second insulated conductive flat band (5b).

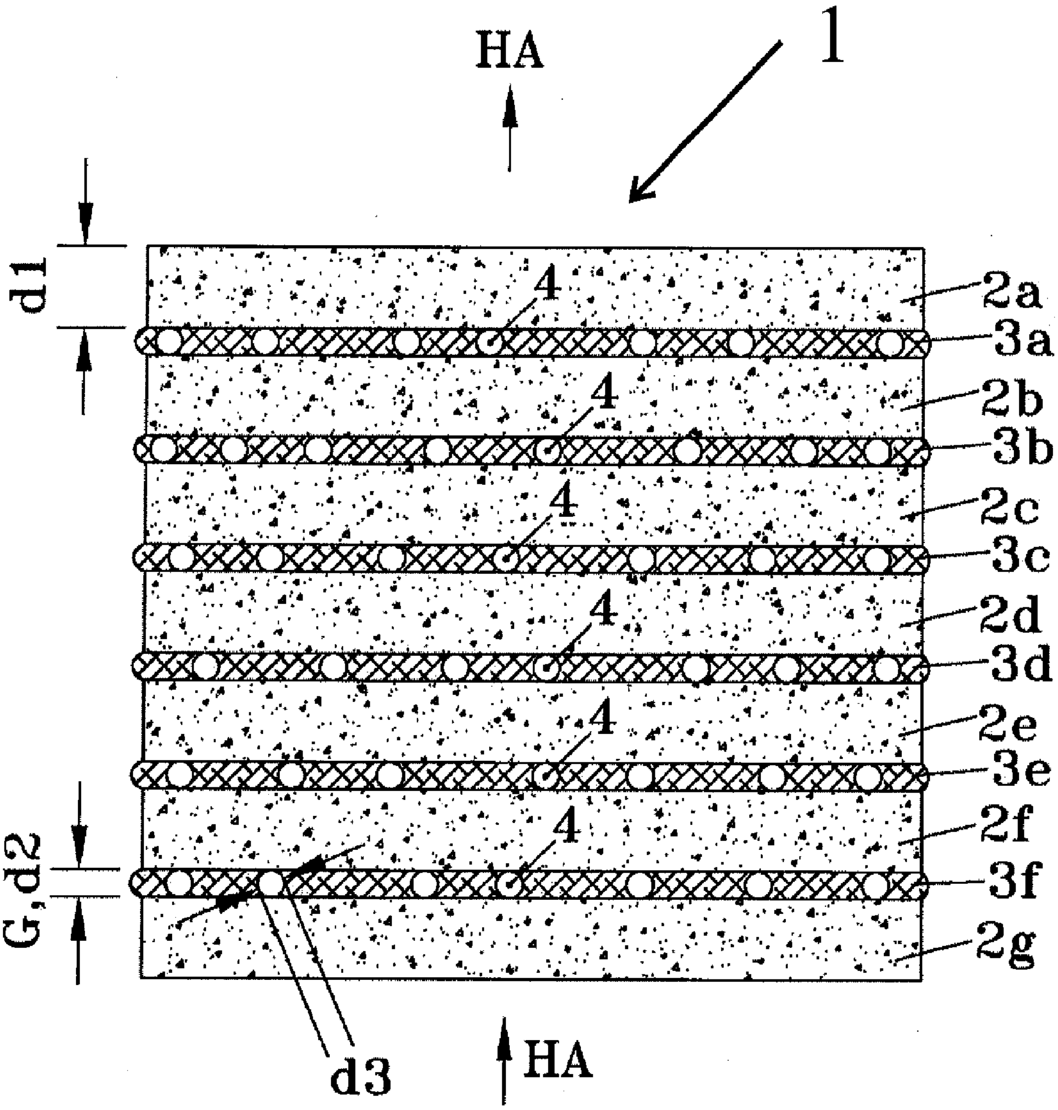

Fig. 1

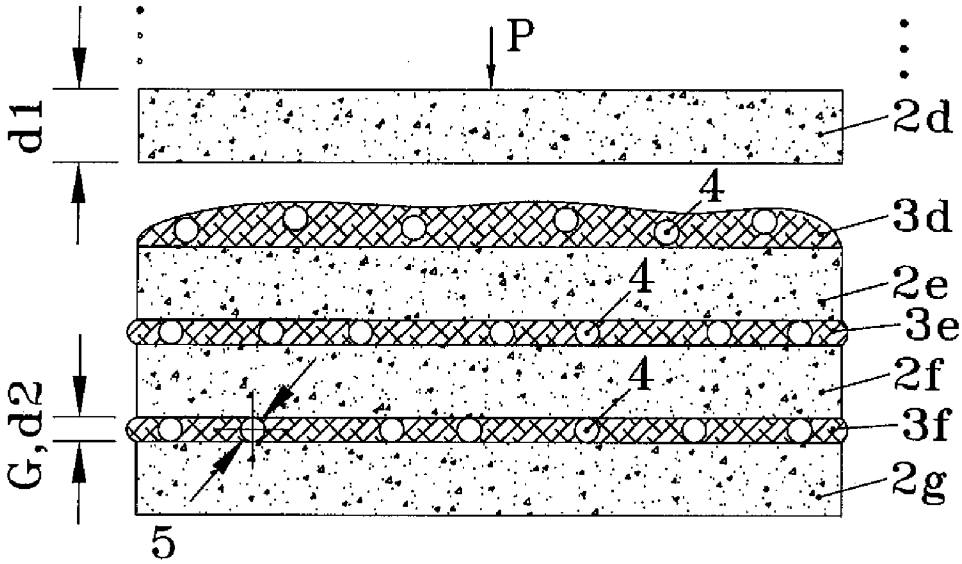

Fig. 2

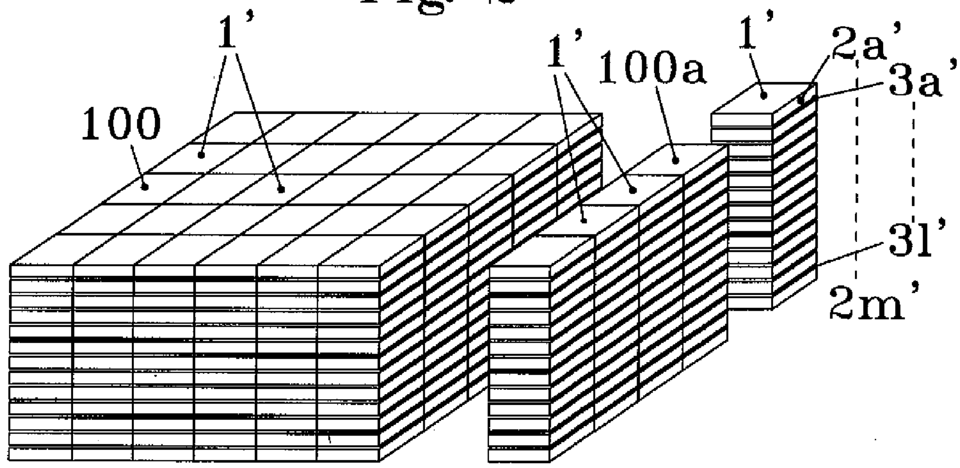

Fig. 3

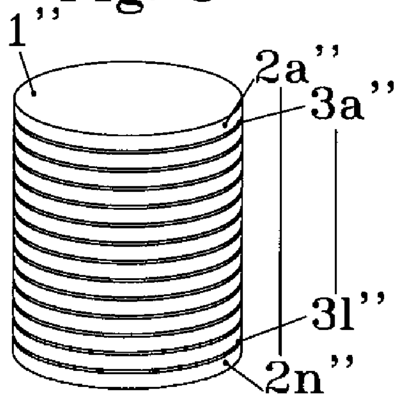

Fig. 4

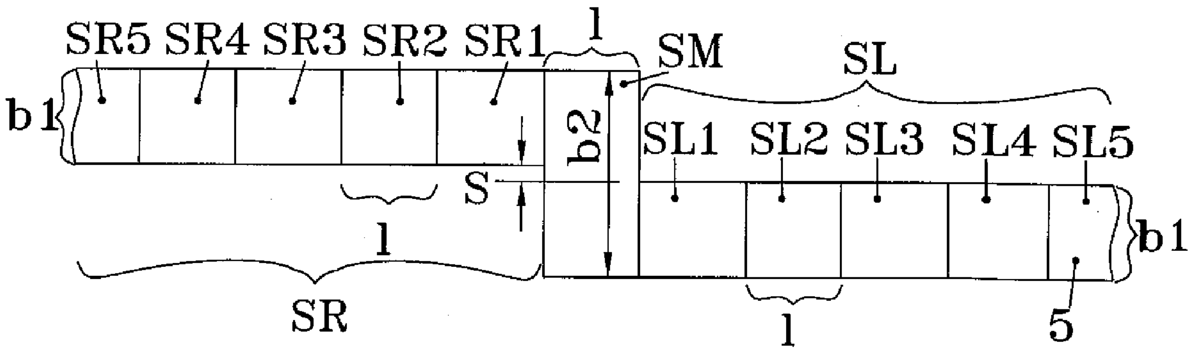

Fig. 5a

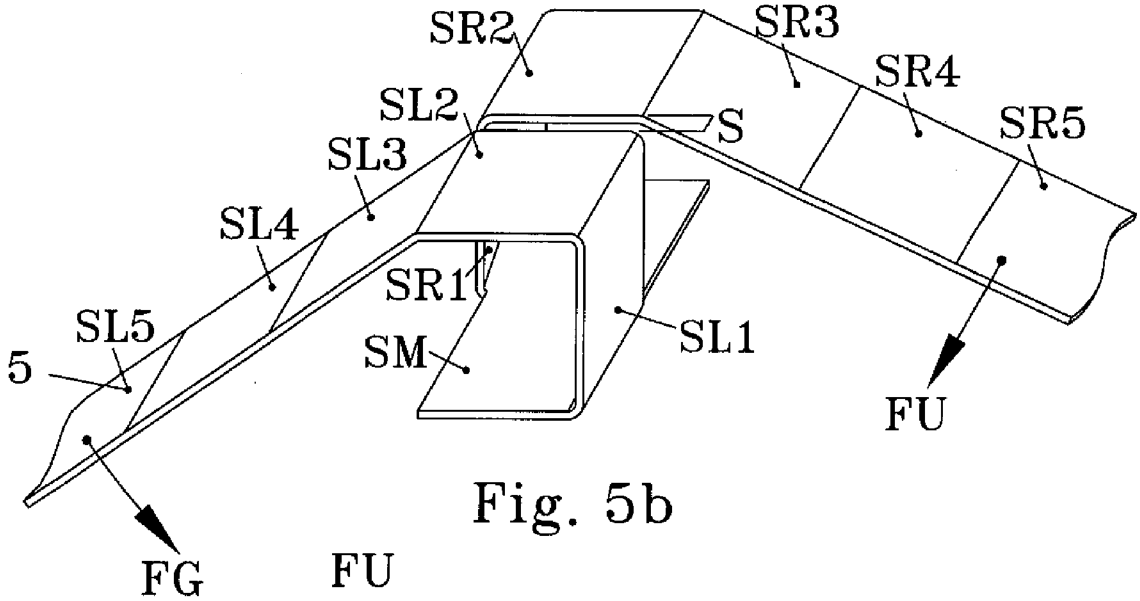

Fig. 5b

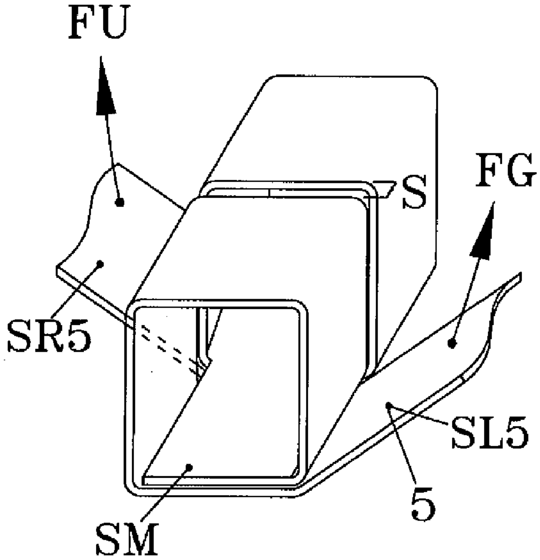

Fig. 5c

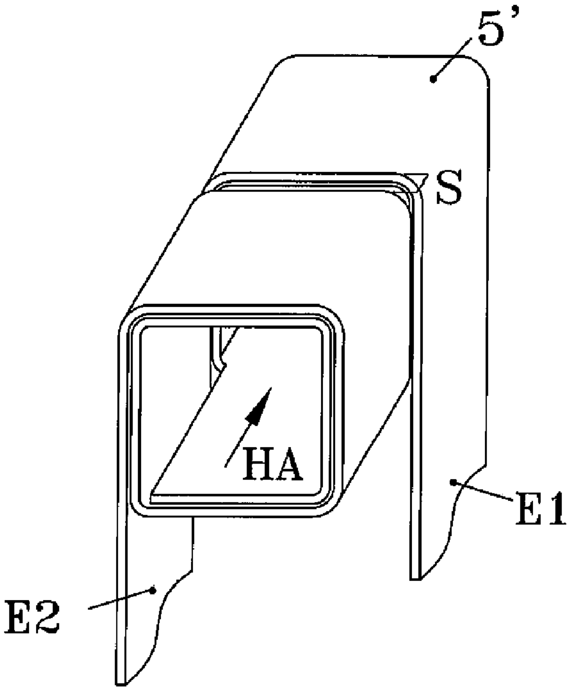

Fig. 6

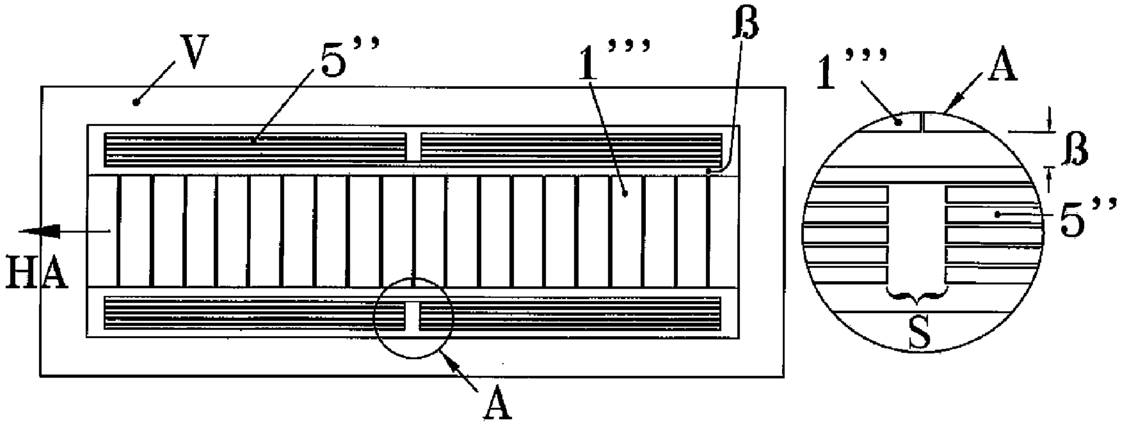

Fig. 7

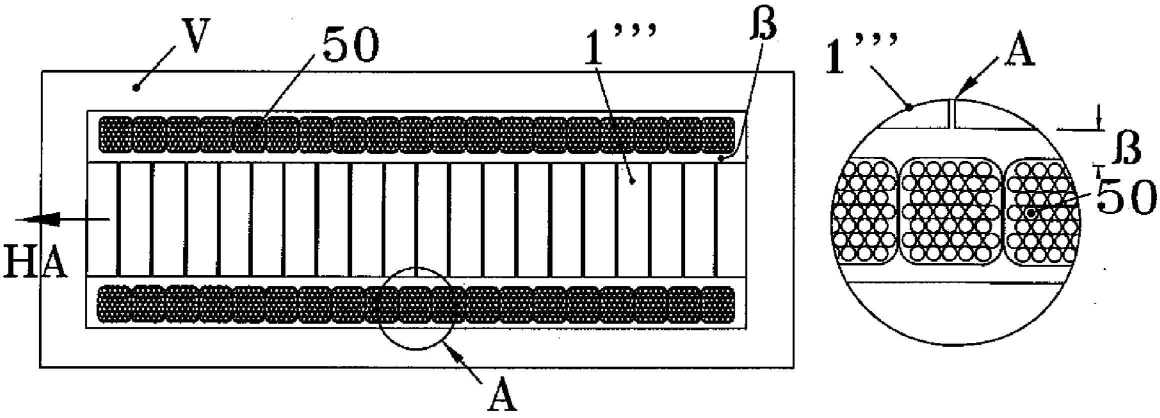

Fig. 8

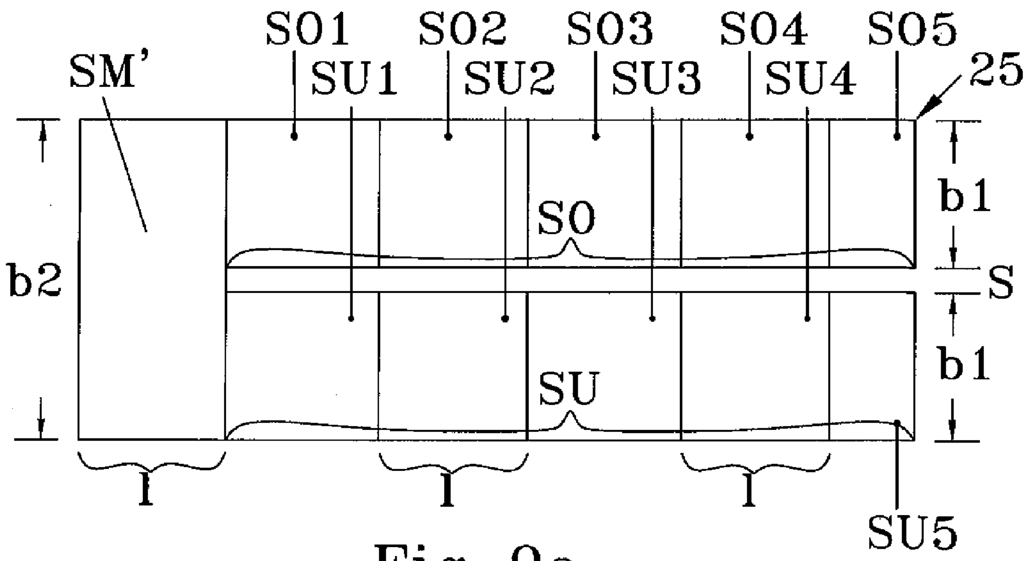

Fig. 9a

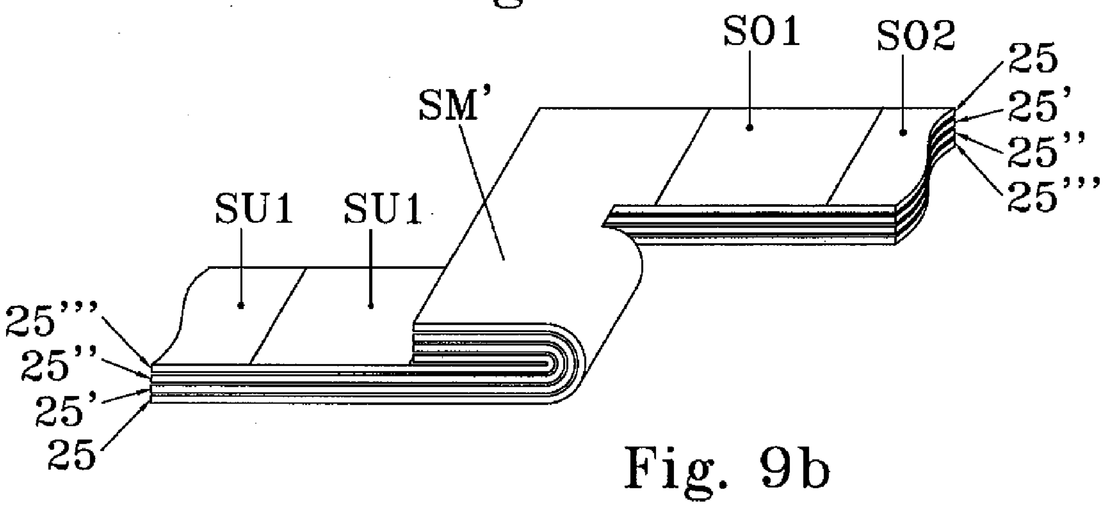

Fig. 9b

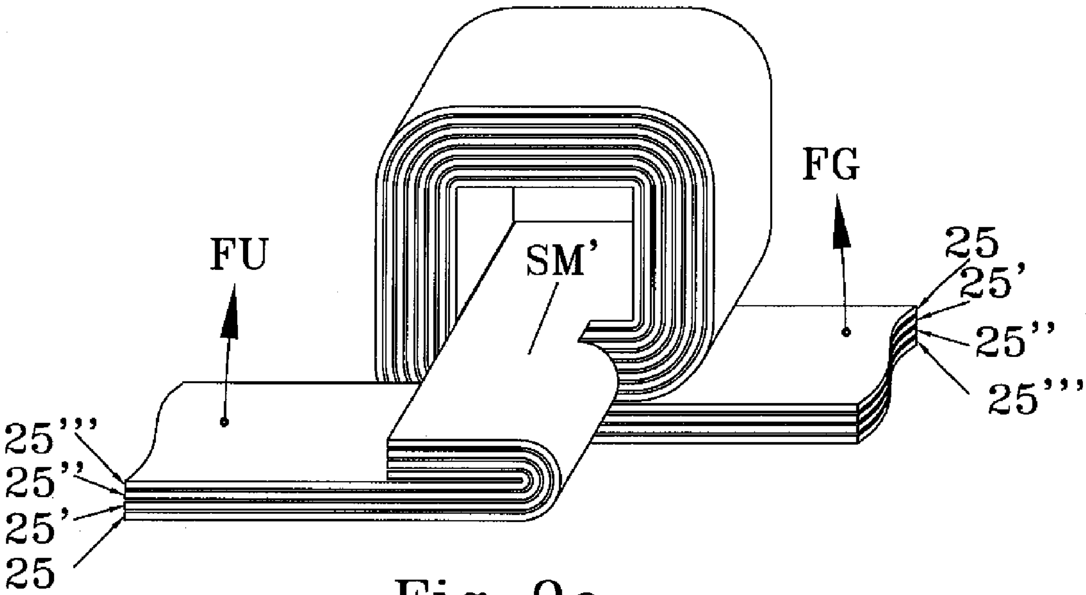

Fig. 9c

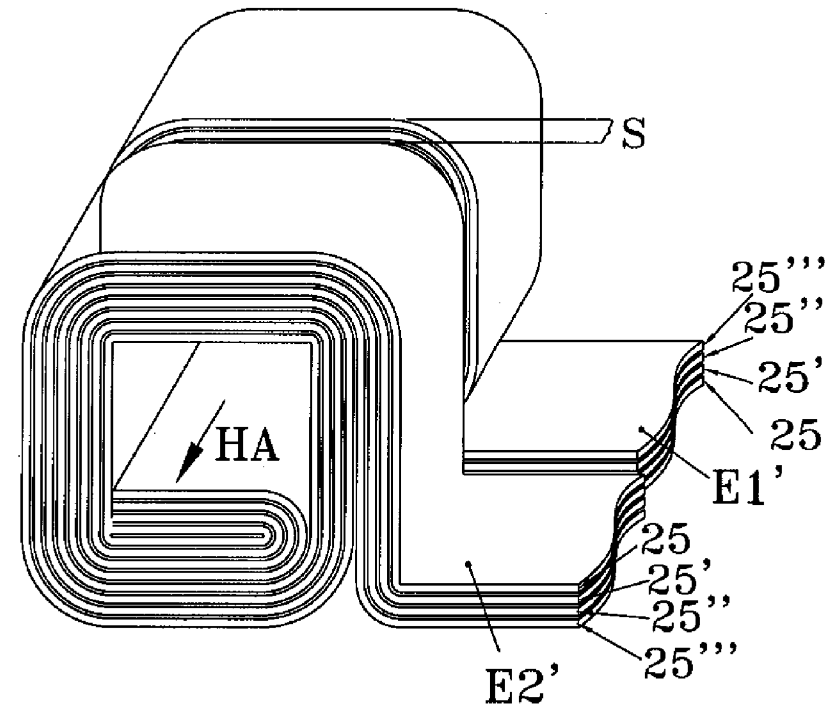

Fig. 10

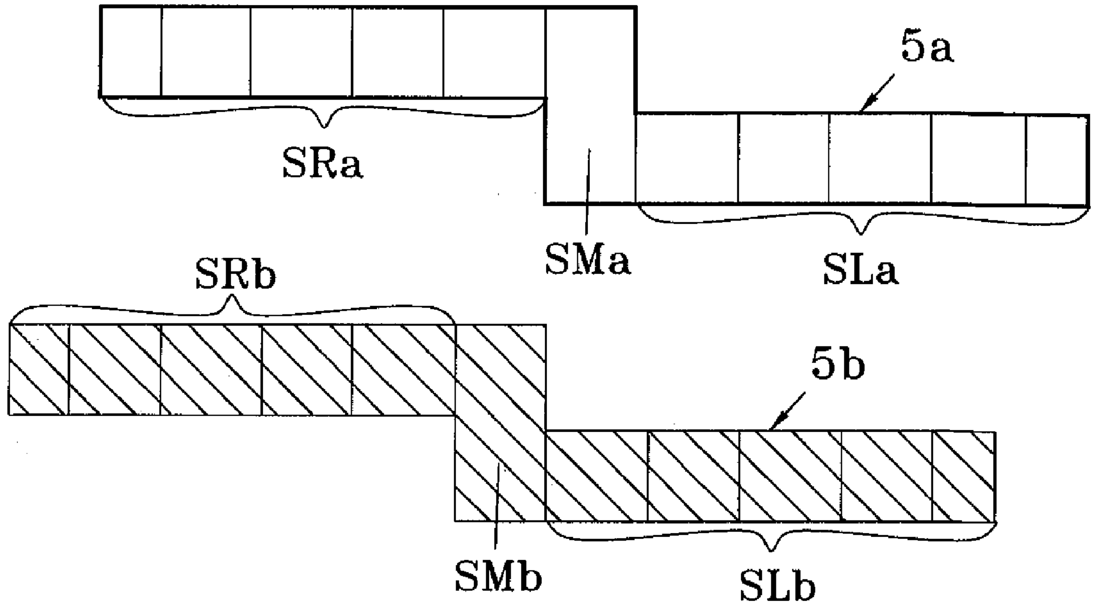

Fig. 11a

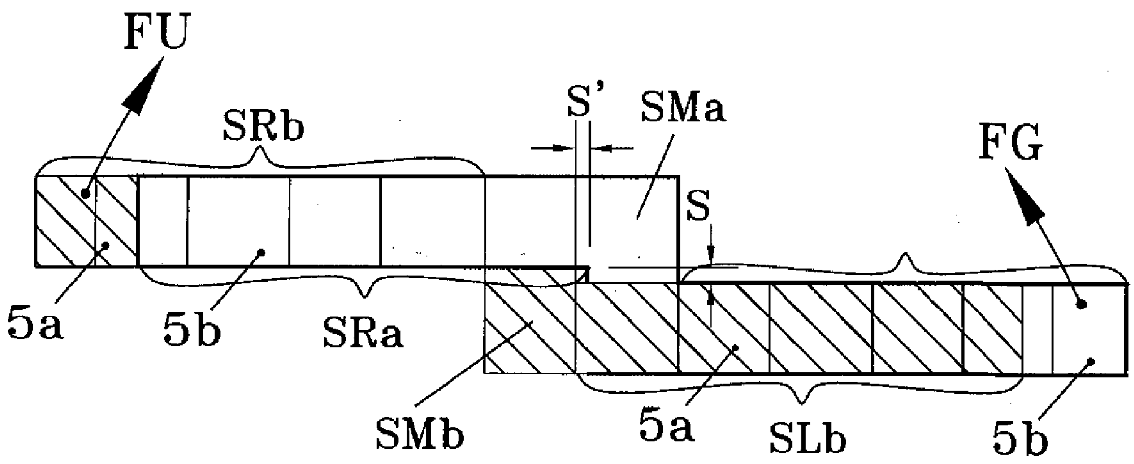

Fig. 11b

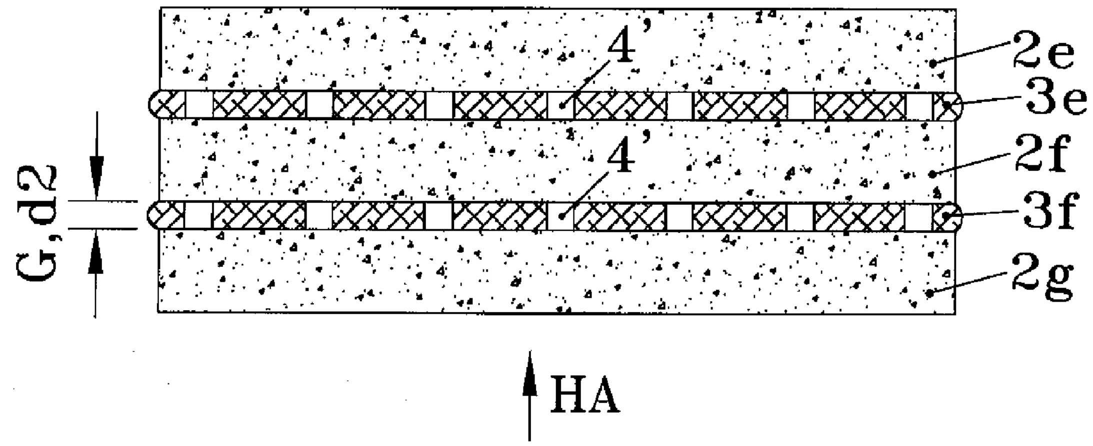

Fig. 12

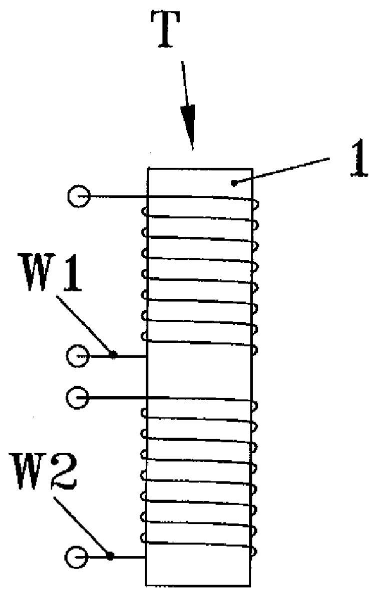

Fig. 13

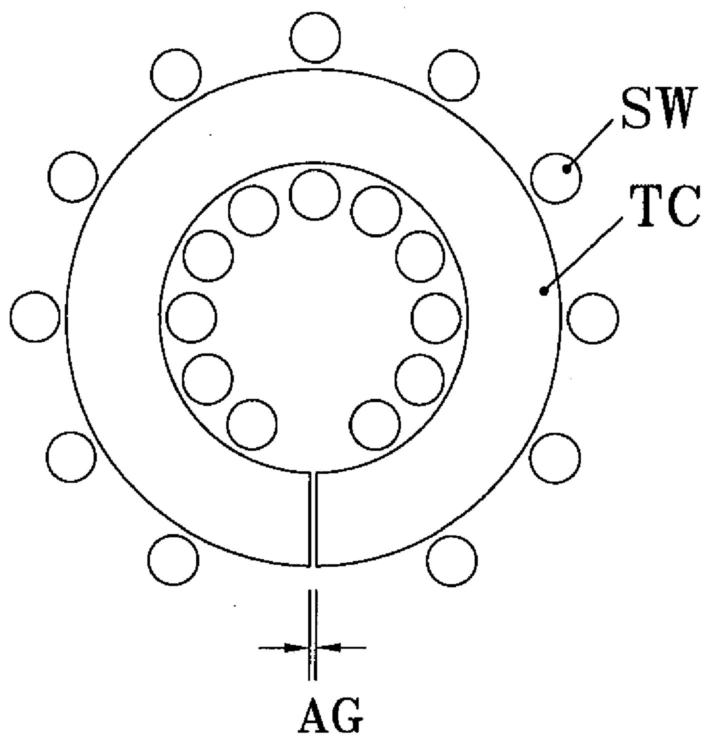

Fig. 14

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EUROPEAN SEARCH REPORT

Application Number
EP 12 17 2102

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	US 6 011 339 A (KAWAKAMI TSUKASA [JP]) 4 January 2000 (2000-01-04) * abstract * * * column 5, line 47 - column 6, line 17; figures 6-8 * * column 8, line 46 - column 9, line 12; figures 21-23 *	1-4	INV. H01F27/28 H01F41/06 ADD. H01F3/14 H01F27/34
X	EP 1 429 352 A1 (CANON KK [JP]) 16 June 2004 (2004-06-16) * paragraphs [0034], [0035]; figure 11 * * paragraphs [0041] - [0043]; figures 13,14 *	1-4	
X	DE 10 2009 008405 A1 (KEIPER GMBH & CO KG [DE]) 19 August 2010 (2010-08-19) * abstract * * * paragraphs [0028] - [0034]; figures 2-4 *	1-4	
X	WO 2007/136288 A1 (IVANOV SERGEY VASILIEVICH [RU]; SKOBLILOV ANDREY NIKOLAEVICH [RU]; SLI) 29 November 2007 (2007-11-29) * abstract; figures 1-9,18-22 *	1-3	TECHNICAL FIELDS SEARCHED (IPC) H01F H02K
X	DE 100 40 415 C1 (ROBERT SEUFFER GMBH & CO KG [DE]) 10 January 2002 (2002-01-10) * abstract; figures 1-5 * * paragraphs [0023] - [0027] *	1-3	
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	10 October 2012	Reder, Michael

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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T : theory or principle underlying the invention
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10-10-2012

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

REFERENCES CITED IN THE DESCRIPTION

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