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(54) **Integrated common mode and differential mode choke**

(57) An apparatus, and a method using the apparatus, for filtering common mode and differential mode currents, wherein the apparatus comprises a first magnetic core element made of a first magnetic material, a second magnetic core element made of a second magnetic material, wherein permeability characteristics of the second magnetic material differ from permeability characteristics of the first magnetic material, and at least one winding, wherein each winding is arranged to magnetize the first and the second magnetic core.

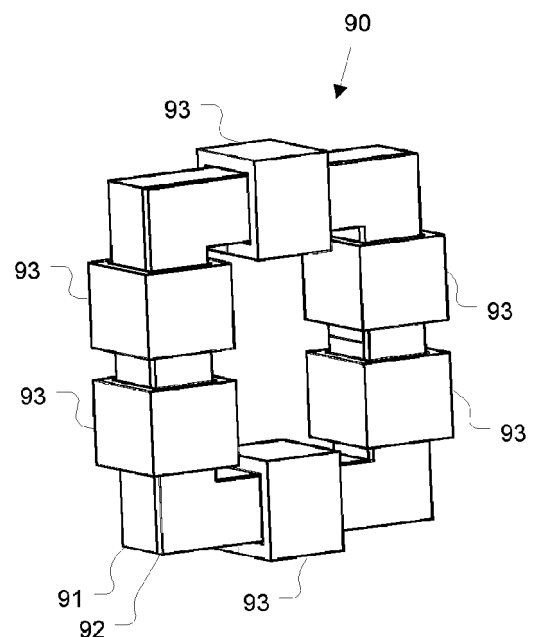


Figure 9a

Description

FIELD OF THE INVENTION

- 5 **[0001]** The present invention relates to differential and common mode chokes, and particularly to integrating the two choke types.

BACKGROUND INFORMATION

- 10 **[0002]** Existing electric drives typically rely on the use of frequency converters. A main circuit of a frequency converter may comprise chokes for damping differential and common mode currents.
- 15 **[0003]** Operational frequencies of differential mode chokes are typically multiples of the fundamental frequency. Depending on the nominal current of a frequency converter, the strain on a differential mode choke in the frequency converter can be thousands of amperes.
- 20 **[0004]** Differential mode chokes can be placed in various places of the main circuit. Figures 1a, 1b, 1c, and 1d illustrate typical positions 10, 11, 12, and 13 for a differential mode choke. In positions 12 and 13, in addition to currents at frequencies multiples of the fundamental frequency, the chokes may also experience currents at the switching frequency, which is typically in a range of few kilohertz.
- 25 **[0005]** Differential mode chokes typically use laminated sheets of iron as the magnetic material of the core. Figures 2a and 2b illustrate an exemplary three phase choke structure 20 and an exemplary one phase choke structure 23, respectively. In Figures 2a, three windings 21 encircle an iron core 22 of the choke 20. The core 22 is divided into three parallel columns. The choke 20 can, for instance, be placed in positions 10, 12, and 13 of Figures 1 a to 1d. In Figure 2b, one winding 24 encircles an iron core 25 of one phase choke 23. The one phase choke 23 can be used in all of the positions 10 to 13 illustrated in Figures 1 a to 1 d.
- 30 **[0006]** Common mode currents can emerge through stray capacitances in the frequency converter. The inverter of the frequency converter can, for instance, function as a common mode voltage source. Paths for the common mode currents depend on the type of grounding and cabling, the structure of the motor, and various other aspects of the operating environment of the whole electric drive. Thus, a main circuit of a frequency converter can also comprise a common mode choke (or several chokes), for instance, for limiting a common mode current to a motor and/or to a grid.
- 35 By limiting the common mode current, bearing currents can be minimized.
- 40 **[0007]** Operational frequencies of the common mode currents are usually higher than operational frequencies of the differential mode currents. The common mode currents may, for instance, be present in a frequency range of 1 kHz to 30 MHz. The maximum currents may have quite large amplitudes while their effective value remains low.
- 45 **[0008]** In addition to the high frequency common mode currents, low frequency circulating currents, which can be classified as common mode currents, may also appear for instance because of parallel-connected components or non-idealities of components. The circulating currents may have higher effective values than the high frequency common mode currents.
- 50 **[0009]** Depending on the purpose of use, common mode chokes can be placed in various positions of the main circuit. Figures 3a, 3b, and 3c illustrate typical positions for common mode chokes 30, 31, and 32.
- 55 **[0010]** Typically, inductances of common mode chokes in a main circuit of a frequency converter are lower than inductances of differential mode chokes. Such common mode chokes are typically constructed using a structure illustrated in Figure 4 wherein toroid shaped magnetic cores 40 are placed around phase conductors 41. The common mode current induces fluxes circulating in the cores 40. A similar structure can be formed by passing DC link bus bars through a toroidal magnetic core or cores. However, making the large bus bars pass through the core can be difficult in high power applications. A bus bar typically makes just one pass through the core. In such structures, a relatively high permeability is required for a desired inductance. As a result, a saturation flux density is usually relatively small, and the material used loses its magnetic properties at relatively low current magnitudes.
- 60 **[0011]** One phase chokes intended for attenuating differential mode currents, such as illustrated in Figure 2b, can also provide a common mode impedance, for instance, when connected to phase conductors of the electric drive. However, the applicability of the choke in Figure 2b to damp common mode currents is reduced by its poor high frequency characteristics. A magnetic material, such as laminated iron sheets, intended for attenuating low frequency currents may lose its magnetic properties at higher frequencies. Thus, it can be unsuitable for attenuating common mode currents at, for instance, 1 kHz to 30 MHz frequencies. Figure 5 illustrates an example of inductance characteristics of an iron core.
- 65 **[0012]** On the other hand, if high frequency attenuation is emphasized, a material with good high frequency characteristics may have a low saturation flux density and a low relative permeability, thus resulting in a physically large choke.
- 70 **[0013]** The three phase core structure of Figure 2a forms a path for a differential mode current but forms no path for a common mode current. A path for the common mode current can be provided by adding another parallel column or columns to the structure illustrated in Figure 2a. Figure 6 illustrates an exemplary core structure 60 with four columns.

The rightmost column in Figure 6 provides a common mode path for fluxes induced by currents in windings 61. However, the characteristics of the magnetic material may cause problems in a manner similar to that in connection with the one phase differential mode choke of Figure 2b. In order to achieve a good high frequency attenuation, the material used may have to have good high frequency performance characteristics and high saturation flux density.

[0014] Separate common mode and differential mode filters can be connected in series in order to achieve adequate common mode and differential mode attenuation. This may, however, be an expensive solution since at least two separate filters are required.

[0015] EP2104117B1 discloses choke arrangements with common mode and differential mode attenuating properties. In the arrangements, each phase has two windings, and each winding is connected in series with a rectifier. Thus, a structure where the flux always flows in one direction in the core is achieved. This also allows a path for the common mode flux. The structure is applicable to one phase chokes and three phase chokes.

[0016] In EP2104117B1, the windings and the core dimensioned on the basis of the differential mode inductance result in a relatively high common mode inductance. However, as the magnetic material of the core is selected by emphasizing the low frequency characteristics, an effective common mode inductance is present only within a limited (low) frequency range.

BRIEF DISCLOSURE

[0017] An object of the present invention is to provide a method and an apparatus so as to alleviate the above disadvantages. The objects of the invention are achieved by a method and an apparatus which are characterized by what is stated in the independent claims. Preferred embodiments of the invention are disclosed in the dependent claims.

[0018] A common mode choke and a differential mode choke can effectively be integrated into one structure by using two parallel magnetic core elements. One of the magnetic circuits can be dedicated to differential mode attenuation and another to common mode attenuation. The magnetic core elements can be magnetized using a set of windings which magnetizes both elements. The magnetic material can be selected such that a typically larger differential current does not saturate the core element dedicated to the common mode attenuation. As the differential mode current no longer saturates the core element dedicated to the common mode attenuation, the core element can be manufactured by using a relatively small amount of material, thus lowering the manufacturing costs. The inductance of the core element can also have higher values at higher frequencies and currents because now the common mode current alone determines the saturation flux density. Further, cooling of the integrated cores and the windings can be centralized.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] In the following, the invention will be described in greater detail by means of preferred embodiments with reference to the accompanying drawings, in which

Figures 1a, 1b, 1c, and 1d illustrate typical positions for a differential mode choke;
 Figure 2a and 2b illustrate an exemplary three phase choke structure and an exemplary one phase choke structure;
 Figures 3a, 3b, and 3c illustrate typical positions for a common mode choke;
 Figure 4 illustrates an exemplary common mode choke structure;
 Figure 5 illustrates an example of inductance characteristics of an iron core;
 Figure 6 illustrates an exemplary core structure with four columns;
 Figure 7 illustrates a simplified equivalent magnetic circuit of an exemplary single winding of an apparatus with a first magnetic core element and a second magnetic core element;
 Figure 8 illustrates an example of permeability characteristics;
 Figures 9a and 9b illustrate an exemplary embodiment of the disclosed apparatus and method; and
 Figure 10 illustrates another exemplary embodiment.

DETAILED DISCLOSURE

[0020] The present disclosure presents an apparatus and a method for filtering common mode and differential mode currents. The method can be based on the use of the disclosed apparatus. The apparatus comprises a first magnetic core element, a second magnetic core element, and at least one winding, each winding being arranged to magnetize the first and the second magnetic core.

[0021] The first magnetic core element is made of a first magnetic material, and the second magnetic core element is made of a second magnetic material. Permeability characteristics of the second magnetic material differ from permeability characteristics of the first magnetic material. Permeability changes as a function of frequency so the magnetic materials can be selected such that a ratio between a permeability of the first magnetic material and a permeability of

the second magnetic material changes as a function of frequency.

[0022] The magnetic material and the structure of a magnetic core can be used for determining a magnetic reluctance of the core. The reluctance of the magnetic core can be seen as an indicator of how good a magnetic conductor the core is. The reluctance of a magnetic core can be calculated as follows:

$$R_m = \frac{l}{\mu_{eff} A}, \quad (1)$$

wherein l is the length of a magnetic circuit of the core, μ_{eff} is the permeability of the core material, and A is the cross-sectional area of the magnetic circuit.

[0023] As permeability changes as a function of frequency, the reluctance is also responsive to frequency. Thus, magnetic materials and structures of the first and the second magnetic core can be selected such that a low frequency magnetic flux induced by low frequency currents flows mostly in the first magnetic core element while a high frequency flux induced by high frequency currents flows mostly in the second magnetic core. Differential mode currents and low frequency common mode currents can, for instance, represent the above-mentioned low frequency currents while high frequency common mode currents can represent the above-mentioned high frequency currents.

[0024] For instance, the reluctances of the first and the second magnetic core can be designed such that the reluctance of the first magnetic core element is lower than the reluctance of the second magnetic core element at frequencies lower than a first frequency while, at the same frequency as or at higher frequencies than the first frequency, the reluctance of the first magnetic core element is higher than the reluctance of the second magnetic element.

[0025] Figure 7 illustrates a simplified equivalent magnetic circuit of an exemplary single winding 70 of an apparatus with a first magnetic core element and a second magnetic core element. A low frequency current i_{DM} flows together with a low frequency current i_{CM} in the winding 70. The low frequency current may, for instance, be a differential mode current. The high frequency current may, for instance, be a common mode current. A first magnetic flux Φ_{DM} induced by the low frequency current i_{DM} and a second flux Φ_{CM} induced by the high frequency current i_{CM} flow in the first and the second magnetic core element.

[0026] A reluctance $R_{m,DM}$ of the first magnetic core element is represented by a series connection of a first core reluctance $R_{m,DM,core}$ and a first air gap reluctance $R_{m,DM,air}$. Correspondingly, a reluctance $R_{m,CM}$ of the second magnetic core element is represented by a series connection of a second core reluctance $R_{m,CM,core}$ and a second air gap reluctance $R_{m,CM,air}$. To prevent the first magnetic flux Φ_{DM} from flowing in the second magnetic core element, the reluctance $R_{m,DM}$ of the first magnetic core element can be designed much lower than the reluctance $R_{m,CM}$ of the second magnetic core element at low frequencies.

[0027] This can be accomplished, for instance, by maximizing an effective permeability of the first magnetic core element and by using an air gap as small as possible. Maximizing the effective permeability $\mu_{eff,DM}$ of the first magnetic core element minimizes the first core reluctance $R_{m,DM,core}$, and minimizing the air gap minimizes the first air gap reluctance $R_{m,DM,air}$. At the same time, a second material and an air gap of the second magnetic core element can be chosen such that the desired difference between the reluctances of the first and the second magnetic core is achieved at low frequencies. The air gaps of the magnetic circuits of the first magnetic core element and the second magnetic core element can have different lengths. The first magnetic flux Φ_{DM} and a ratio in which the magnetic flux Φ_{DM} is shared between the first magnetic core element and the second magnetic core element are determined on the basis of the reluctances $R_{m,DM}$ and $R_{m,CM}$ of the first and the second magnetic core element.

[0028] The first magnetic material can be selected such that it has good operational characteristics at low frequencies. At frequencies lower than a second frequency, for instance 1 Mhz, the effective permeability $\mu_{eff,DM}$ of the first magnetic material may be higher than the effective permeability $\mu_{eff,CM}$ of the second magnetic material. The second magnetic material can be selected such that it preserves its effective permeability $\mu_{eff,CM}$ at higher frequencies, resulting in the permeability $\mu_{eff,DM}$ of the first magnetic material being lower than the permeability $\mu_{eff,CM}$ of the second magnetic material at the same frequency as or at higher frequencies than the second frequency. In this manner, the reluctance $R_{m,DM}$ of the first magnetic core element can be designed such that the first magnetic flux Φ_{DM} flows mainly through the first magnetic core element at low frequencies.

[0029] However, the effective permeability $\mu_{eff,DM}$ of the first magnetic material decreases in response to an increase in frequency. If the permeability $\mu_{eff,DM}$ of the first magnetic material decreases, the reluctance $R_{m,DM,core}$ of the first core element increases, as can be seen in Equation 1. As a result, the reluctance $R_{m,DM}$ of the first magnetic core element increases in response to frequency. When the second material is selected such that it preserves its effective permeability $\mu_{eff,CM}$ at higher frequencies, the reluctance $R_{m,DM}$ increases above the reluctance $R_{m,CM}$ of the second magnetic core element at higher frequencies. Thus, a second magnetic flux Φ_{CM} induced by the high frequency current

i_{CM} flows mainly in the second core element.

[0030] Figure 8 illustrates an example of permeability characteristics of the first and the second magnetic material. At lower frequencies, a relative permeability μ_{CM} of the second magnetic material is lower than a relative permeability μ_{DM} of the first magnetic material. In Figure 8, the relative permeability μ_{CM} is lower than the relative permeability μ_{DM} at frequencies below 1 MHz. At higher frequencies, however, the first magnetic material loses almost all its relative permeability μ_{DM} while the second magnetic material preserves most of its relative permeability μ_{CM} .

[0031] The above-disclosed apparatus and method can be used in various locations of an electric drive, for instance, in the positions described in Figures 1a to 1d and 3a to 3d. The structure of an apparatus according to the disclosure can also be implemented in various ways. For instance, a structure similar to either of the structures described in Figures 2b and 6 can be used, with the exception of the core structure being a composite of two magnetic core elements.

[0032] Figures 9a and 9b illustrate an exemplary embodiment of the disclosed apparatus and method. In Figure 9a, a three phase choke 90 is made of two magnetic core elements 91 and 92 which are arranged next to each other. Six windings 93 encircle the magnetic core elements 91 and 92. Each winding 93 magnetize both core elements 91 and 92.

[0033] Figure 9b shows a simplified schematic view of an arrangement using the choke 90 of Figure 9a. A DC link 94 is supplied by a grid 95 through the choke 90 and an active rectifier bridge 96. The windings 93 of the apparatus 90 are arranged to magnetize the magnetic core elements 91 and 92 in the same direction. In other words, the flux always flows in one direction in the magnetic core elements 91 and 92. As illustrated in Figure 9b, this is accomplished by connecting the rectifiers of the active rectifier bridge 96 in series with the windings 93. This arrangement also provides a path for the common mode flux in the core elements 91 and 92.

[0034] The cross-sectional area and the magnetic material of the first magnetic core element 91 in Figure 9a can be dimensioned for the low frequency currents which, typically, are differential mode currents. At the same time, the cross-sectional area and the magnetic material of the second magnetic core element 92 can be dimensioned for the higher frequency currents which, typically, are common mode currents. Thus, the cross-sectional areas of the magnetic circuits of the first magnetic core element and the second magnetic core element can be different from each other.

[0035] Figure 10 illustrates another exemplary embodiment where a first magnetic core element 101 and a second magnetic core element 102 do not run physically next to each other all the way. The elements 101 and 102 are physically next to each other only where they are encircled by a winding 103.

[0036] Since the first and the second core are not physically next to each other all the way through the magnetic circle, the ratio between the lengths of their magnetic circuits can be adjusted. In other words, the lengths of the magnetic circuits of the first magnetic core element and the second magnetic core element can be different from each other. By adjusting the length l of the magnetic circuit of a core, the reluctance of the core can be modified, for instance, according to Equation 1. On the other hand, the placement of the windings 103 in Figure 10 is constrained to the area where the cores are physically next to each other.

[0037] It will be obvious to a person skilled in the art that, as technology advances, 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 apparatus for filtering common mode and differential mode currents, wherein the apparatus comprises a first magnetic core element constructed out of a first magnetic material, a second magnetic core element made of a second magnetic material, wherein permeability characteristics of the second magnetic material differ from permeability characteristics of the first magnetic material such that a ratio between a permeability of the first magnetic material and a permeability of the second magnetic material is adapted to change as a function of frequency, and at least one winding, wherein each winding is arranged to magnetize the first and the second magnetic core.
2. An apparatus according to claim 1, wherein a reluctance of the first magnetic core element is higher than a reluctance of the second magnetic core element at frequencies lower than a first frequency, and the reluctance of the first magnetic core element is lower than the reluctance of the second magnetic core element at the same frequency as or at higher frequencies than the first frequency.
3. An apparatus according to claim 2, wherein a permeability of the first magnetic material is higher than a permeability of the second magnetic material at frequencies lower than a second frequency, and the permeability of the first magnetic material is lower than the permeability of the second magnetic material at the

same frequency as or at higher frequencies than the second frequency.

4. An apparatus according to any one of claims 1 to 3, wherein lengths of magnetic circuits of the first magnetic core element and the second magnetic core element are different from each other.
5. An apparatus according to any one of claims 1 to 4, wherein cross-sectional areas of the magnetic circuits of the first magnetic core element and the second magnetic core element are different from each other.
6. An apparatus according to any one of claims 1 to 5, wherein air gaps of the magnetic circuits of the first magnetic core element and the second magnetic core element have different lengths.
7. An arrangement comprising an apparatus according to any one of claims 1 to 6, wherein windings of the apparatus are arranged to magnetize magnetic core elements in the same direction.
8. A method of filtering common mode and differential mode currents by using an apparatus comprising a first magnetic core element made of a first magnetic material, a second magnetic core element made of a second magnetic material, wherein permeability characteristics of the second magnetic material differ from permeability characteristics of the first magnetic material such that a ratio between a permeability of the first magnetic material and a permeability of the second magnetic material is adapted to change as a function of frequency, and at least one winding, each winding being arranged to magnetize the first and the second magnetic core.

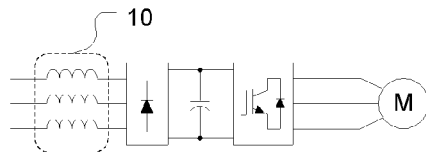


Figure 1a

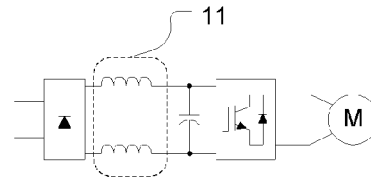


Figure 1b

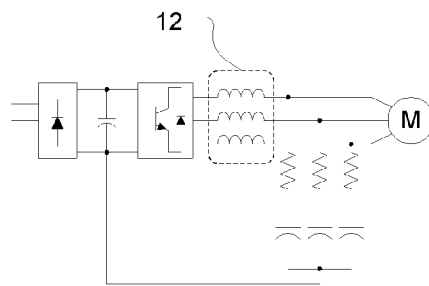


Figure 1c

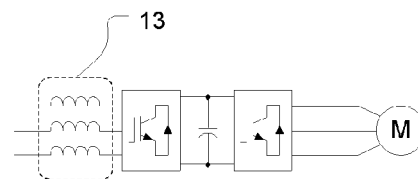


Figure 1d

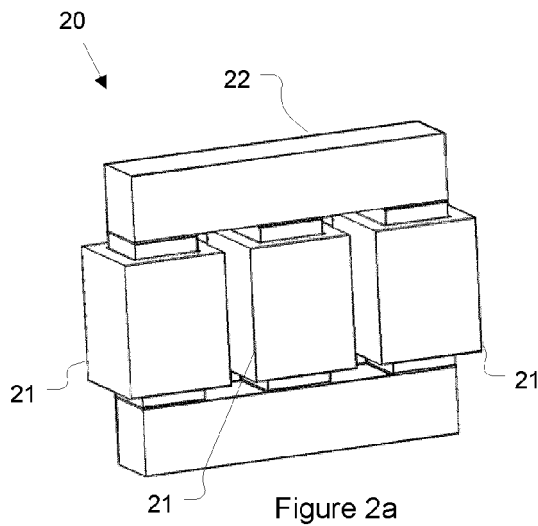


Figure 2a

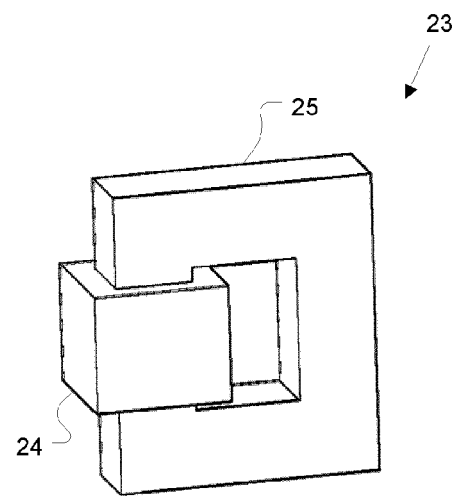


Figure 2b

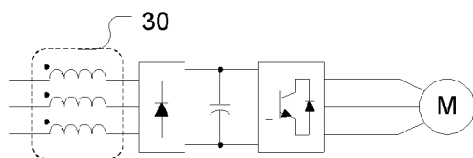


Figure 3a

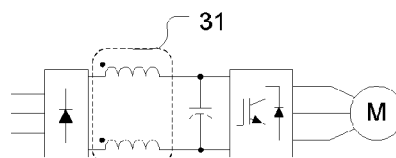


Figure 3b

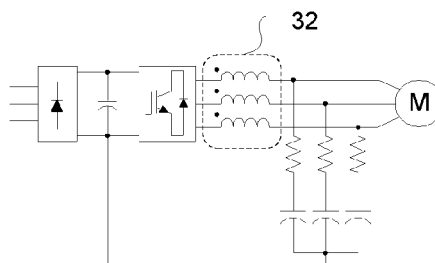


Figure 3c

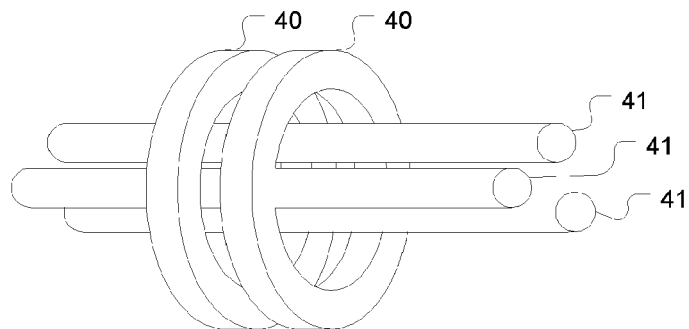


Figure 4

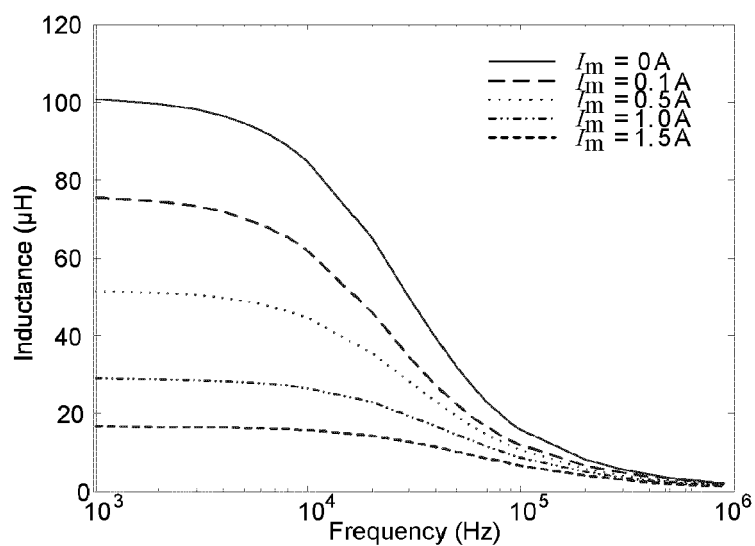


Figure 5

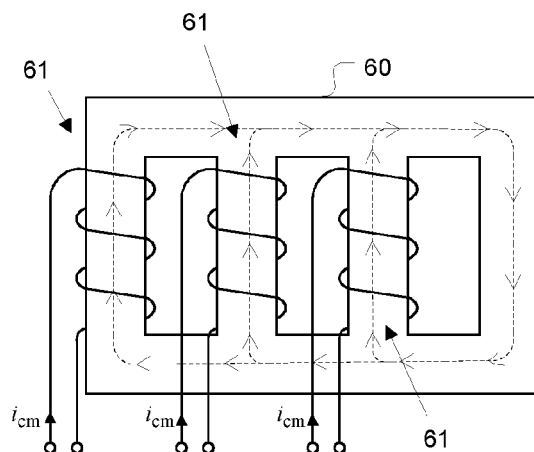


Figure 6

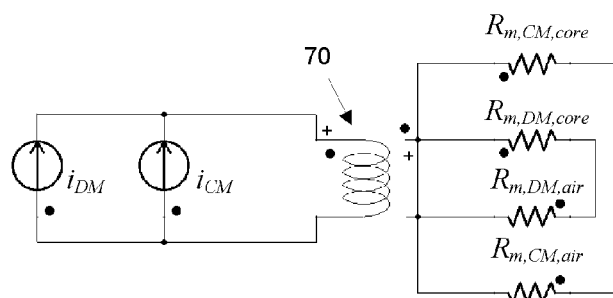


Figure 7

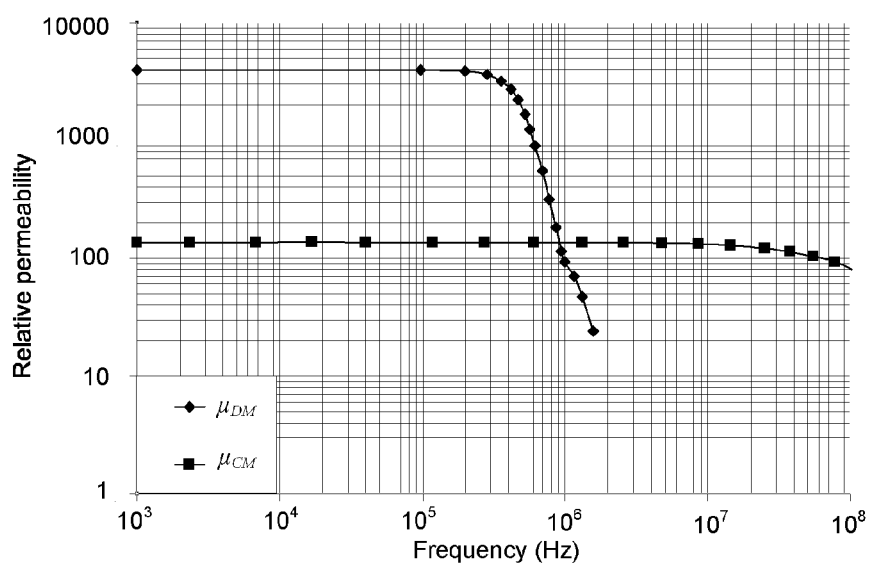


Figure 8

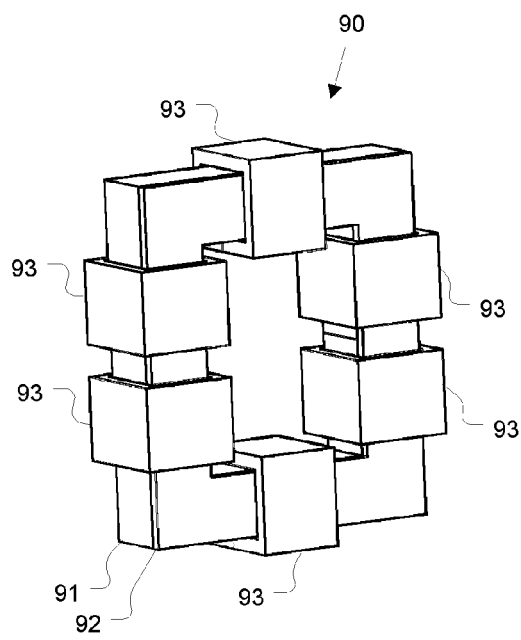


Figure 9a

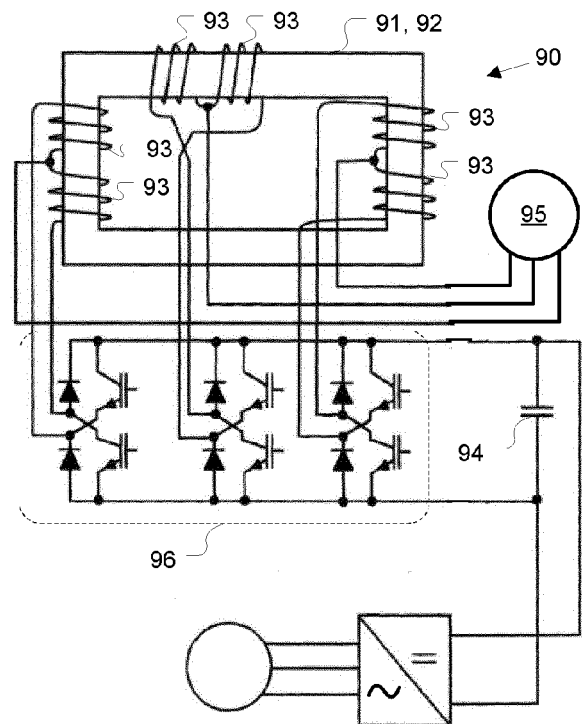


Figure 9b

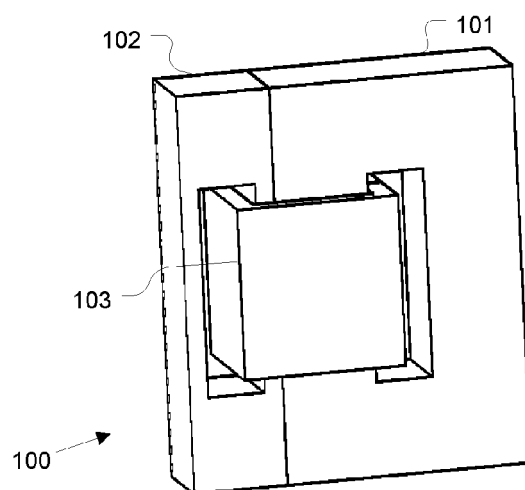


Figure 10



EUROPEAN SEARCH REPORT

Application Number
EP 12 15 7111

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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Y	* column 1, line 1 - column 6, line 13 * * figures 1-13 *	7	
X	----- WO 89/07828 A1 (RIEDI JOKS SUSANNE [CH]) 24 August 1989 (1989-08-24) * abstract * * page 1, paragraph 1 - page 11, paragraph 1 * * figures 1-20 *	1-8	
Y,D	----- EP 2 104 117 B1 (ABB OY [FI]) 7 July 2010 (2010-07-07) * abstract * * column 1, paragraph 3 - column 3, paragraph 7 * * column 6, paragraph 15 - column 8, paragraph 20 * * columns 10,11, paragraph 27 * * figures 1a,1b,2,5 *	1-5,7,8	
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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 20 August 2012	Examiner Kardinal, Ingrid
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			

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EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
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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
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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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