

DESCRIPTION

Title of the invention: Encapsulated magnetic component

[0001] The present invention relates to planar magnetic components, such as inductors, coupled inductors and transformers. More specifically, the invention relates to an innovative technique for encapsulating planar magnetic components.

[0002] Conventional magnetic components often have limitations in terms of size, weight and performance in extreme environments of space. Currently available solutions are often based on conventional configurations that are not optimized for the specific constraints of space, notably size and weight reduction, resistance to radiation, and thermal stability.

[0003] The present invention relates to planar magnetic components specifically designed to meet the stringent requirements of the space industry. These components use advanced design and manufacturing technologies to deliver improved performance, a significant reduction in size and weight, reduced power consumption, reduced electrical and magnetic losses, and increased thermal stability.

[0004] In general, a planar magnetic component according to the prior art comprises an inductive element formed on a printed circuit and composed of windings consisting of several turns. These windings are designed to generate a magnetic field that can be used for energy storage (inductor) or transfer (transformer). The planar magnetic component also incorporates a ferromagnetic core used to channel the magnetic field, thereby forming a magnetic circuit. This core can be made from different materials depending on the specific intended application, taking into account criteria such as power, frequency, price, size and required performance. The assembly formed by the printed circuit, the inductive element, and the ferromagnetic core are molded in an encapsulation structure made of a solidified rigid resin. This type of planar magnetic component presents a technical problem relating to the integration of the ferromagnetic core in a rigid encapsulating resin. During operation, the ferromagnetic core undergoes shape variations at its outer surface by magnetostrictive effect. Magnetostrictive effect is a physical phenomenon in which a material changes shape in response to an applied magnetic field. When a magnetostrictive material is exposed to a magnetic field, the magnetic domains of the

material realign, resulting in a change in its crystalline structure. This change of structure causes a mechanical deformation of the material, which results in a change of shape observable on a macroscopic scale. However, the ferromagnetic core is subjected to mechanical stress, applied by the contact surface with the rigid encapsulation structure, in response to magnetostrictive deformation. Said mechanical stress considerably degrades the performance of the planar magnetic component during operation. Degradation of the performance of the magnetic component results in:

- a considerable increase in magnetic reluctance and therefore iron losses; and
- a considerable reduction in the equivalent inductance of the magnetic component, up to 90% compared to a theoretical inductance value calculated during design.

[0005] To overcome the limitations of existing solutions, the invention proposes a planar magnetic component molded in an innovative encapsulation structure. The encapsulation structure according to the invention is composed of a rigid housing filled with a material having a high elasticity so as to relieve the mechanical stress applied by the encapsulation structure on the molded ferromagnetic core. The elastic material also ensures thermal compatibility with the rigid housing.

[0006] In addition, the rigid housing of the encapsulation structure is dimensioned so that the printed circuit and the ferromagnetic core can be inserted into the rigid housing, thereby providing a non-contact mechanical interlock between the rigid housing and the ferromagnetic core. This eliminates the mechanical stress applied to the ferromagnetic core in response to the deformations resulting from the magnetostrictive effect. Thus, the magnetic component according to the invention solves the aforementioned problems of degradation of electromagnetic performance (magnetic guidance and equivalent inductance) without reducing the robustness of the magnetic component against stresses (radiation, temperatures, particles, etc.) relating to a use in space.

[0007] The invention relates to a magnetic component comprising:

- an active portion comprising:
 - o a printed circuit extending in a first plane;

- o a first inductive element formed by a first winding of an electrical conductor deposited on the printed circuit;
- o a ferromagnetic core positioned with respect to said first inductive element so as to form a closed magnetic circuit capable of guiding a magnetic field induced by the first inductive element; and
- an encapsulation structure configured to encapsulate the active portion and comprising a solid housing made of a first material having a first Young's modulus; wherein the housing is filled with a filling resin having a second Young's modulus lower than the first Young's modulus;

10 and the ferromagnetic core is molded in said resin inside said housing so as to separate the ferromagnetic core from said housing.

[0008] According to a specific aspect of the invention, the first Young's modulus is between 10 GPa and 20 GPa.

15 [0009] According to a specific aspect of the invention, the second Young's modulus is between 1 MPa and 20 MPa.

[0010] According to a specific aspect of the invention, the first material is a solidified epoxy polymer.

[0011] According to a specific aspect of the invention, the filling resin is a polysiloxane or an acrylic.

20 [0012] According to a specific aspect of the invention, the housing comprises:

- a first notch made in a first face of the housing;
- a second notch made in a second face of the housing parallel to said first face;

the first face and the second face being orthogonal to the first plane; the printed circuit having a first end inserted by sliding into the first notch and having a second end inserted by sliding into the second notch.

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[0013] According to a specific aspect of the invention, the magnetic component further comprises a sealing layer made of an adhesive material deposited between:

- on the one hand the first end and on the other hand the periphery of the first notch; and
- between on the one hand the second end and on the other hand the periphery of the second notch.

5 [0014] The invention also relates to a method for manufacturing a magnetic component comprising the following steps:

- providing an active portion comprising:
 - o a printed circuit extending in a first plane;
 - o a first inductive element formed by a first winding of an electrical conductor
- 10 deposited on the printed circuit; the first winding defining a central zone of the printed circuit delimited by said first winding; the printed circuit comprising a first opening located in the central zone;
 - o a ferromagnetic core forming a closed magnetic circuit and comprising a rod traversing the first opening;
- 15 - manufacturing a solid housing made of a first material having a first Young's modulus; the housing comprising:
 - o a first notch made in a first face of the housing; a second notch made in a second face of the housing parallel to said first face; and a second opening on a third face of the housing orthogonal to said first face;
- 20 - placing the active portion in the housing through the second opening by inserting the integrated circuit by sliding through the first and second notches;
- filling the solid housing through the second opening with a filling resin having a second Young's modulus greater than the first Young's modulus so as to mold at least the ferromagnetic core.

25 [0015] According to a specific aspect of the invention, the manufacturing method further comprises the following step:

- depositing a sealing layer made of an adhesive material between:

- o on the one hand the first end and on the other hand the periphery of the first notch; and
- o between on the one hand the second end and on the other hand the periphery of the second notch;

5 so as to seal the first face and the second face.

[0016] Other features and advantages of the present invention will become more clearly apparent on reading the following description with reference to the following appended drawings.

10 [0017] Figure 1 illustrates a perspective view of the magnetic component according to the invention.

[0018] Figure 2a illustrates an exploded perspective view of a first example of the active portion of the magnetic component according to the invention.

[0019] Figure 2b illustrates an exploded perspective view of a second example of the active portion of the component according to the invention.

15 [0020] Figure 3 illustrates a perspective view of the rigid housing of the magnetic component according to the invention.

[0021] Figure 4a illustrates a perspective view of the magnetic component cut in the plane (X,Z) according to the invention.

20 [0022] Figure 4b illustrates a sectional view in the plane (X,Z) of the magnetic component according to the invention.

[0023] Figure 5 illustrates a sectional view in the plane (Y,Z) of the magnetic component according to the invention.

[0024] Figure 6 illustrates a top view of the magnetic component according to the invention.

25 [0025] Figure 7 illustrates a flowchart of the method for manufacturing the magnetic component according to the invention.

30 [0026] Figure 1 illustrates a perspective view of the assembled magnetic component D1 according to the invention. The assembled magnetic component D1 is placed in an orthogonal spatial frame of reference (X,Y,Z) and the perspective view described in figure 1 is taken from the same side as the plane (X,Z).

[0027] The magnetic component D1 comprises an active portion 1 encapsulated in an encapsulation structure 2. The active portion 1 comprises a printed circuit 10, at least one inductive element 11 and a ferromagnetic core 12. The printed circuit 10 extends in a first plane P1 parallel to the plane (X,Y). At least one inductive element 11 is

5 formed by a first winding 11 of an electrical conductor deposited on the printed circuit 10. The ferromagnetic core 12 is a body made of a ferromagnetic material forming a closed magnetic circuit. The ferromagnetic core 12 is placed with respect to the first winding 11 so as to guide a magnetic field induced by the first inductive element 11.

[0028] The encapsulation structure 2 comprises a solid housing 21 made of a first

10 material having a first Young's modulus. The housing 21 is filled with a filling resin 22 having a second Young's modulus lower than the first Young's modulus. The active portion 1 is molded in the filling resin 22 inside the housing 21. The housing 21 comprises a first notch 21a made in a first face 211 of the housing 21. The housing 21 further comprises a second notch 21b made in a second face 212 of the housing

15 parallel to said first face 211. The housing 21 has an opening 21c on a third face 213 orthogonal to the two faces 211 and 212. The active portion 1 is placed inside the housing 21, through the opening 21c, by inserting the printed circuit 10 by sliding into the notches 21a, 21b. The printed circuit 10 thus extends in a plane P1 orthogonal to the first face 211, to the second face 212 and to the third face 213.

[0029] The ferromagnetic core 12 is molded in the filling resin 22 having a second

20 Young's modulus lower than the first Young's modulus. The ferromagnetic core 12 is thus separated from the rigid housing 21 by the filling resin 22. This makes it possible to relieve the mechanical stress applied to the outer surfaces of the ferromagnetic core 12 and thus absorb the mechanical deformations related to the magnetostrictive

25 effect. This results in a reduction of the magnetic reluctance compared with the solutions of the prior art, as well as an equivalent increase in the inductance value of the active portion 1. Furthermore, the rigid housing 21 provides mechanical and electrical protection for the active portion with respect to the external environment.

[0030] The first material forming the housing 21 has a first Young's modulus of

30 between 10 GPa and 20 GPa. The filling resin 22 has a second Young's modulus of between 1 MPa and 20 MPa. Advantageously, the first Young's modulus is 500 to 1000 times greater than the second Young's modulus. By way of non-limiting example, the housing 21 is made of a solidified epoxy polymer, preferably an epoxy

polymer filled with silica beads, to improve its rigidity. By way of non-limiting example, the filling resin 22 is made of a polysiloxane or an acrylic. These materials are suitable for use in space applications: they exhibit a reduced outgassing rate and can withstand multiple thermal cycling characterization tests in accordance with

5 space industry standards.

[0031] Thus, the use of the filling resin in the encapsulation structure allows, on the one hand, the magnetostriction required for the proper functioning of the magnetic component and, on the other hand, a good thermal interface with the housing.

[0032] Furthermore, the first material forming the housing 21 has a first coefficient of thermal expansion and the filling resin 22 has a second coefficient of expansion greater than the first coefficient of thermal expansion. This prevents delamination at the interface between the filling resin 22 and the inner walls of the housing 21.

[0033] Figure 2a illustrates an exploded perspective view of a first example of the active portion 1 of the magnetic component D1 according to the invention. The first inductive element 11 is formed by a first winding 11 of an electrical conductor deposited on the printed circuit 10. For example, the first winding 11 is formed by printed copper tracks. Advantageously, the printed circuit 10 is a multi-layer printed circuit used to obtain a compact magnetic component D1 over several levels.

[0034] The first winding 11 defines a central zone 101 of the printed circuit 10. The central zone 101 is delimited by the inner tracks of the first winding 11. The printed circuit 10 comprises a first opening 102 located in the central zone 101. The ferromagnetic core 12 is formed by two bodies 12a, 12b, made of ferrite for example, joined together by means of an adhesive layer. The joining of the two bodies 12a, 12b forms a ferromagnetic core 12 in the form of a closed magnetic circuit capable of guiding a magnetic field. The assembled ferromagnetic core 12 thus consists of a frame and a central rod 121. The central rod 121 results from the assembly of the rod 121a and the rod 121b. The central rod 121 is inserted into the first opening 102 located in the central zone 101. The frame of the ferromagnetic core 12 surrounds the first winding 11. Indeed, the printed circuit also comprises two lateral openings 102' and 102'' placed on both sides of the outer tracks of the first winding 11. The two ferromagnetic bodies 12a and 12b are assembled so as to obtain a frame having two sides inserted in said lateral openings 102' and 102''. This provides a closed

magnetic circuit capable of guiding a magnetic field induced by the first inductive element (11).

[0035] Figure 2b illustrates an exploded perspective view of a second example of the active portion 1 of the magnetic component D1 according to the invention. The technical advantages and features described with respect to the first example also apply to the second example. The second example differs from the first example by the absence of lateral openings in the printed circuit 10. Indeed, the frame of the ferromagnetic core 12 surrounds the printed circuit 10. This is an alternative to the embodiment described in the first example.

[0036] Figure 3 illustrates a perspective view of the rigid housing 21 of the magnetic component D1 according to the invention. The housing 21 comprises a first notch 21a made in a first face 211 of the housing 21. The housing 21 further comprises a second notch 21b made in a second face 212 of the housing parallel to said first face 211. The housing 21 has an opening 21c on a third face 213 orthogonal to the two faces 211 and 212. The active portion 1 is placed inside the housing 21, through the opening 21c, by inserting the printed circuit 10 by sliding into the notches 21a, 21b. The printed circuit 10 thus extends in a plane P1 orthogonal to the first face 211, to the second face 212 and to the third face 213. The thickness of the walls of the rigid housing 21 is greater than or equal to 1 mm to ensure its mechanical robustness.

[0037] In addition, the depth of each notch 21a, 21b along the Y axis is chosen so that: once the printed circuit 10 has been completely inserted by sliding through the two slots 21a, 21b, the ferromagnetic core 12 assembled with said printed circuit 10 is not in contact with any internal part of the housing 21.

[0038] Figure 4a illustrates a perspective view of the magnetic component D1 cut in the plane (X,Z) according to the invention. Figure 4b illustrates a sectional view in the plane (X,Z) of the magnetic component D1 according to the invention.

[0039] The central rod 121 of the ferromagnetic core 12 is inserted into the first opening 102 located in the central zone 101. The outer surfaces of the ferromagnetic core 12 are in contact with the elastic filling resin 22 and not with the rigid housing 21 (with the exception of the interface with the periphery of the opening 102). This permits the deformations by magnetostrictive effect and therefore an adaptation of the crystalline structure of the ferromagnetic core 12 according to the realignment of

the magnetic domains in said ferromagnetic core 12. The printed circuit 10 has a first end 10a inserted by sliding into the first notch 21a and a second end 10b inserted by sliding into the second notch 21a. The width L1 of the printed circuit 10 is greater than the width L2 of the rigid housing 21. Thus, the two ends 10a, 10b project beyond the rigid housing 21 along the axis X through the notches 21a, 21b. At least one of the ends 10a, 10b comprises electrical contact points enabling the magnetic component D1 to be electrically incorporated into an external circuit and/or device. For example, the external circuit is a larger printed circuit comprising other analog or digital electronic components or optoelectronic components or power components.

[0040] The magnetic component D1 further comprises a sealing layer 3, 3' made of an adhesive material deposited between, on the one hand, the first end 10a and, on the other hand, the periphery of the first notch 21a; and between, on the one hand, the second end 10b and, on the other hand, the periphery of the second notch 21b.

[0041] Figure 5 illustrates a sectional view in the plane (Y,Z) of the magnetic component D1 according to the invention. This sectional view shows how the frame of the ferromagnetic core 12 surrounds the printed circuit 10 so as to form a closed magnetic circuit. The magnetic field induced by the first inductive element 11 is guided in a first loop formed by the central rod 121 and the left-hand portion of the frame along Y. In addition, the magnetic field induced by the first inductive element 11 is guided in a second loop formed by the central rod 121 and the right-hand portion of the frame along Y. The opening 21c is blocked by the filling resin 22.

[0042] Figure 6 illustrates a top view of the magnetic component D1 according to the invention. Each of the ends 10a, 10b of the printed circuit 10 projects beyond the housing 21 through the lateral notches 21a, 21b. Each of the ends 10a, 10b of the printed circuit 10 comprises a plurality of castellated vias V1. The castellated vias VA are semi-circular connection vias at the edge of the printed circuit 10. The castellated vias V1 allow on the one hand the interconnection between the different layers of the printed circuit 10, and on the other hand facilitate attachment of the magnetic component to an external device by allowing soldering.

[0043] Figure 7 illustrates a flowchart of the method P1 for manufacturing the magnetic component D1 according to the invention.

[0044] The first step E1 consists of providing an active portion 1 comprising:

- o a printed circuit 10 extending in a first plane P1;
- o a first inductive element 11 formed by a first winding 11 of an electrical conductor deposited on the printed circuit 10. The first winding 11 defines a central zone 101 of the printed circuit 10 delimited by the first winding 11. The printed circuit 10 comprises a first opening 102 located in the central zone 101.
- o a ferromagnetic core 12 forming a closed magnetic circuit and comprising a rod 121 traversing the first opening 102.

[0045] The second step E2 consists of manufacturing a solid housing 21 made of a first material having a first Young's modulus. The housing 21 comprises a first notch 21a made in a first face 211 of the housing. The housing further comprises a second notch 21b made in a second face 212 of the housing parallel to said first face 211. The housing further comprises an opening 21c on a third face 213 of the housing 21 orthogonal to said first face 211.

[0046] In order to manufacture the housing 21, it is possible to manufacture each face of said housing separately from a resin. The faces of the housing are made, for example, of epoxy. The first and second faces 211, 212 are machined so as to form the notches 21a, 21b. In order to form the opening 21c, the third face 213 is not manufactured (the absence of the third face 213 corresponds to the opening 21c). The different faces are then assembled together to obtain the shape of the housing 21. The assembled structure is then solidified by thermal annealing to obtain the rigid housing 21.

[0047] Alternatively, it is possible to manufacture the housing 21 using additive manufacturing techniques such as 3D printing.

[0048] The third step E3 consists of placing the active portion 1 in the housing 21 through the second opening 21c by inserting the integrated circuit 10 by sliding through the first and second notches 21a, 21b.

[0049] Optionally, the fourth step E4 consists of depositing a sealing layer 3 made of an adhesive material between, on the one hand, the first end 10a and, on the other hand, the periphery of the first notch 21a. Another adhesive layer 3' is deposited between on the one hand the second end 10b and on the other hand the periphery of

the second notch 21b. This seals the first face 211 and the second face 212 of the housing 21.

[0050] The last step E5 consists of filling the rigid housing 21 with a filling resin 22 through the second opening 21c. The filling resin 22 has a second Young's modulus
5 lower than the first Young's modulus. All the elements of the active portion 1 placed inside the rigid housing 21 are thus molded in the filling resin 22.

CLAIMS**1.** A magnetic component (D1) comprising:

- an active portion (1) comprising:
 - o a printed circuit (10) extending in a first plane (P1);
 - 5 o a first inductive element (11) formed by a first winding (11) of an electrical conductor deposited on the printed circuit (10);
 - o a ferromagnetic core (12) positioned with respect to said first inductive element (11) so as to form a closed magnetic circuit capable of guiding a magnetic field induced by the first inductive element (11); and

- an encapsulation structure (2) configured to encapsulate the active portion (1) and comprising a housing (21) made of a first material having a first Young's modulus; wherein the housing (21) is filled with a filling resin (22) having a second Young's modulus lower than the first Young's modulus;

and the ferromagnetic core (12) is molded in said resin (22) inside said housing so as to separate the ferromagnetic core (12) from said housing (21).

2. The magnetic component (D1) as claimed in claim 1 wherein the first Young's modulus is between 10 GPa and 20 GPa.**3.** The magnetic component (D1) as claimed in either one of claims 1 and 2 wherein the second Young's modulus is between 1 MPa and 20 MPa.**4.** The magnetic component (D1) as claimed in any one of claims 1 to 3 wherein the first material is a solidified epoxy polymer.**5.** The magnetic component (D1) as claimed in any one of claims 1 to 4 wherein the filling resin (22) is a polysiloxane or an acrylic.**6.** The magnetic component (D1) as claimed in any one of claims 1 to 5 wherein the housing (21) comprises:

- a first notch (21a) made in a first face (211) of the housing;

- a second notch (21b) made in a second face (212) of the housing parallel to said first face (211);

the first face (211) and the second face (212) being orthogonal to the first plane (P1);

the printed circuit (10) having a first end (10a) inserted by sliding into the first notch

5 (21a) and having a second end (10b) inserted by sliding into the second notch (21b).

7. The magnetic component (D1) as claimed in claim 6 further comprising a sealing layer (3, 3') made of an adhesive material deposited between:

- on the one hand the first end (10a) and on the other hand the periphery of the first notch (21a); and

10 - between on the one hand the second end (10b) and on the other hand the periphery of the second notch (21b).

8. A method (P1) for manufacturing a magnetic component (D1) comprising the following steps:

- providing (E1) an active portion (1) comprising:

15 o a printed circuit (10) extending in a first plane (P1);

o a first inductive element (11) formed by a first winding (11) of an electrical conductor deposited on the printed circuit (10); the first winding (11) defining a central zone (101) of the printed circuit (10) delimited by said first winding (11); the printed circuit (10) comprising a first opening (102) located in the central zone (101);

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o a ferromagnetic core (12) forming a closed magnetic circuit and comprising a rod (121) traversing the first opening (102);

- manufacturing (E2) a solid housing (21) made of a first material having a first Young's modulus; the housing (21) comprising:

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o a first notch (21a) made in a first face (211) of the housing; a second notch (21b) made in a second face (212) of the housing parallel to said first face (211); and a second opening (21c) on a third face (213) of the housing (21) orthogonal to said first face (211);

- placing (E3) the active portion (1) in the housing (21) through the second opening (21c) by inserting the integrated circuit (10) by sliding through the first and second notches (21a, 21b);
- filling (E5) the solid housing (21) through the second opening (21c) with a filling resin (22) having a second Young's modulus greater than the first Young's modulus so as to mold at least the ferromagnetic core (12).

9. The method (P1) for manufacturing a magnetic component (D1) as claimed in claim 8 further comprising the step of:

- depositing (E4) a sealing layer (3) made of adhesive material between:
 - o on the one hand the first end (10a) and on the other hand the periphery of the first notch (21a); and
 - o between on the one hand the second end (10b) and on the other hand the periphery of the second notch (21b);

so as to seal the first face (211, 212) and the second face.