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(54) Title: ELECTRICAL DEVICE

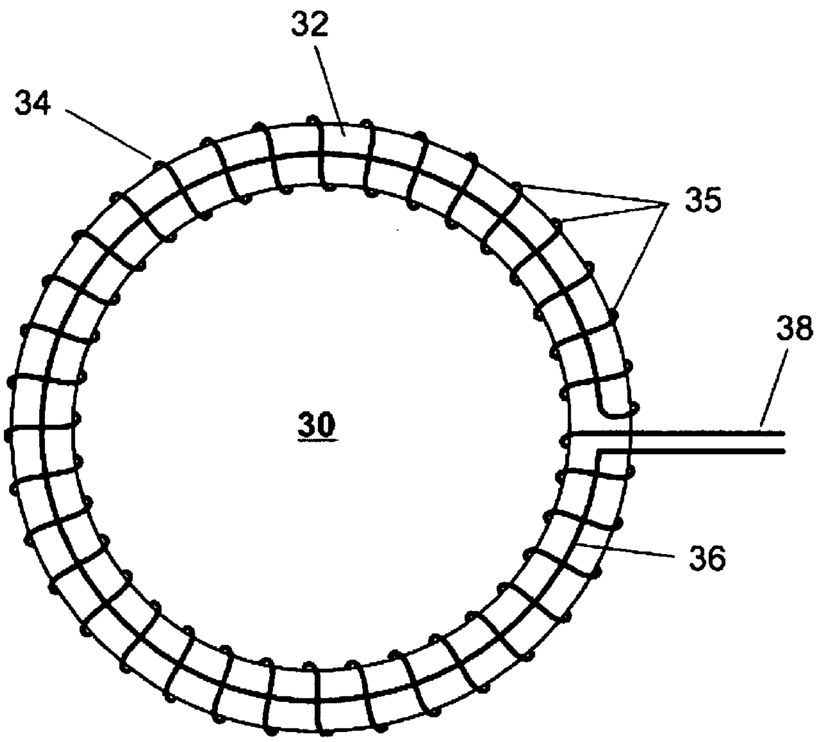

Fig. 7

[Continued on next page]

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(57) Abstract: The invention is related to an electrical device (30, 40) for measuring alternating current or current pulses which comprises at least one coil (34, 42) of electrically conductive wire being wound around a non-magnetic carrier (10, 20, 26, 32, 50), whereas the non-magnetic carrier (10, 20, 26, 32, 50) is made of glass.

Electrical device

Description

The invention relates to an electrical device for measuring alternating current or current pulses which consists of a coil of wire preferably wound around a non-magnetic carrier, which preferably has constant cross sectional area and which forms a closed or almost closed loop. Such a device is commonly known as Rogowski Coil which is widely used as device for measuring alternating current (AC) or current pulses. This type of coil has many advantages over other types of current sensors, though there are some disadvantages, too.

The Rogowski coils are typically constructed by applying an electrically conductive wire on a non-magnetic and non-conductive carrier, which is commonly a plastic based structure and forms a closed or almost closed loop, such that a kind of toroidal coil of wire is formed, wherein the wire is arranged in a helix on a toroidal carrier so that a toroidal coil is formed. The lead from one end of the coil may return through the centre of the coil or close to centre of the coil to the other end, so that both terminals are at the same end of the coil and so that the toroidal coil itself does not form a closed loop, like in Fig. 7. The return wire may not be required in some applications.

The Rogowski coil belongs to the category of air-core coils since the carrier of the coil is non-magnetic, i.e. its magnetic susceptibility is significantly smaller than one. The carrier may be rigid or flexible and its shape may be toroidal or like an oval ring, but other shapes are also possible. Additionally, the Rogowski coil may consist of one single coil, as exemplary shown in Fig. 7, or of an arrangement of multiple coils, as exemplary shown in Fig. 8, in which case the shape of the coils may be straight or curved.

When placed around a primary conductor carrying an electrical current, the Rogowski coil generates a voltage proportional to the derivative of the current according to the Ampere's law. The voltage is also proportional to the number of turns per unit length and to the area of the turns. The area of one turn is equal to the area enclosed by one single complete turn and is approximately equal to the cross section area of the coil carrier.

Since the voltage induced in the Rogowski coil is proportional to the rate of change of current in the primary conductor, the output of the coil is typically connected to an electronic device where the signal is integrated and eventually further processed in order to provide an accurate signal that is proportional to the current flowing through the primary conductor.

The Rogowski coil has many advantages compared to other types of current measuring devices, the most notable being the excellent linearity due to its non-magnetic core which is not prone to saturation effects. Thus, the Rogowski coil is highly linear even when subjected to large currents, such as those used in electric power transmission, welding, or pulsed power applications. Furthermore, since a Rogowski coil has a non-magnetic core, it features very low inductance and can respond both to slow- and fast-changing currents resulting in a particularly wide frequency range of operation. A correctly formed Rogowski coil has winding turns which are uniformly spaced and which have equal or almost equal area in order to be largely immune to electromagnetic interference. A non-magnetic material designates here any material whose magnetic susceptibility has a magnitude or value lower than one.

Despite of the numerous advantages with the use of Rogowski coils mentioned before, the accuracy and the reliability of the Rogowski coil strongly depends on the accuracy and uniformity of the coil winding and of the area of the turns.

The quality of the winding again depends on the winding process and on the coil carrier employed while the area of the turns depends mainly on the coil carrier. The carriers of Rogowski coils typically are manufactured using various types of plastic based materials, thermosetting or thermoplastic. The plastic materials may contain fillers such as glass fiber or silica particles in order to improve their mechanical and dimensional properties.

However, for these plastic based materials it is very difficult to decrease the coefficient of thermal expansion below 25 ppm/K and additionally the coil carriers are subject to deformations caused by mold shrinkage and water absorption. The initial tolerances of plastic based coil carriers cannot be kept within tight limits and can hardly come close to +/-0.05 mm. The moderate tolerances negatively impact the winding process and may affect both the accuracy and the uniformity of the winding turns.

The drifts and deformations of plastic materials are often non-uniform due to anisotropic properties which are induced by the preferential orientation of the polymer molecules and/or glass fiber fillers during the molding process. Non-uniform deformations and non-uniform winding turns decrease the immunity of the Rogowski coil against electromagnetic interference and pick-up of parasitic signals, and result in degraded accuracy and reduced reliability.

The initial error caused by the tolerances of the carrier and the drift caused by the thermal expansion of the carrier are typically too high for high accuracy applications and have to be corrected, e.g. by means of the electronics conditioning the signal of the Rogowski coil, whereas only the errors caused by uniform deformations can be partly corrected. The errors caused by non-uniform deformations and non-uniform winding cannot be reduced. Even in complex systems with sophisticated correction means it is very difficult to ensure good accuracy over wide temperature ranges.

Hence it is an object of the claimed invention to provide an electrical device with a carrier, in particular a Rogowski coil, where the aforementioned problems are overcome while the production is easy and favourable.

This object is achieved by an electrical device for measuring alternating current or current pulses according to the features of claim 1. Further developments and advantageous embodiments are disclosed in further claims and the description.

The electrical device according to the invention comprises at least one coil of electrically conductive wire being wound around a non-magnetic carrier, wherein the non-magnetic carrier is made of glass.

In an advantageous embodiment of the invention the carrier of electrical device, in particular a Rogowski coil, is made of glass by means of a process such as glass molding or pressing. Furthermore, the glass material may consist mainly of silicon dioxide mixed with other components such as Na_2O, CaO, Al_2O_3, B_2O_3, etc.

Depending on the processing method employed, the glass material is formed after being heated at a temperature which exceeds at least the glass transition temperature (Tg). Glass materials with lower Tg can thus be processed at lower temperatures.

Glass does not suffer from mold shrinkage and very good tolerances and surface quality can be obtained. Furthermore, due to the high content of silicon dioxide, glass is featuring excellent physical and chemical stability over very wide temperature range. Its properties feature very low thermal drift, excellent aging withstand, no water absorption, and good solvent resistance. The material is perfectly isotropic due to its amorphous structure, resulting in excellent uniformity of its physical properties. Many types of glasses are commercially available with different physical properties such as different glass transition temperatures and coefficients of thermal expansion.

Best known, most widespread, and lowest cost is the soda-lime glass, which features glass transition temperature of about 570°C and a coefficient of thermal expansion of approximately 9 ppm/K. Significantly lower thermal expansion coefficient can be achieved with other glass types, which may advantageously be used, such as borosilicate glass which is readily available with thermal expansion coefficient around 3 ppm/k and glass transition temperature around 525°C.

In a further embodiment, in order to enhance an easy and beneficial production of the coil carriers preferably glass materials with low glass transition temperature, for example between 200°C and 700°C, are used since their processing parameters result in a remarkable increase of lifetime of molds and reduction of process time. The coefficient of thermal expansion of such glass materials is typically between 2 ppm/K and 15 ppm/K, depending on the particular composition of the material.

Accordingly the coil carriers made of glass exhibit much lower tolerances, better uniformity, wider temperature range, and better stability than hitherto existing and produced plastic based counterparts. Excellent mechanical and chemical stability is ensured including low thermal drift, no long term deformations, no water absorption, and solvent resistance. Moreover, glass materials are widely available and easy to process at competitive cost compared to the plastic based counterparts.

The low tolerances and the uniform structure of the glass carrier make it possible to achieve very uniform winding of the coil necessary to reach high accuracy and high immunity against electromagnetic interference.

Electrical devices according to the invention, as for example Rogowski coils, constructed on glass carriers feature many benefits with respect to prior art coils based on plastic materials. The most important benefits are

- excellent accuracy,
- excellent long-term stability,
- excellent immunity against electromagnetic interference,
- wide operation temperature range,
- no compensation of thermal drifts is needed, and
- about the same production efforts as compared to plastic based carriers.

According to a preferred embodiment the glass carrier of the electrical device, in particular the Rogowski coil, may be formed by traditional molding or pressing techniques with tight tolerances down to +/-0.02 mm and with good surface finish, better than typically achieved with plastic based materials.

Even better tolerances and surface finish can be achieved by employing precision glass molding, a process that was recently developed for fabricating high accuracy but low cost optical components.

Excellent tolerances in the order of +/-0.005 mm and surface roughness in the order of 5 nm are achievable using precision glass molding, much better than with any plastic based material.

Glasses with low glass transition temperature have been developed for precision molding, featuring compositions to decrease the tendency for devitrification and to reduce the reaction with mold materials within the molding temperature range. A wide choice of those glasses exists from various manufacturers and many are also suitable for fabricating coil carriers for electrical devices and in particular for Rogowski coils.

Typical examples of precision molding glasses to be used for manufacturing coil carriers are the P-SK57Q1 type from SCHOTT AG having a transition temperature of 439°C and a coefficient of thermal expansion of 8.9 ppm/K, or the L-PHL1 type from Ohara Corporation having a transition temperature of 347°C and a coefficient of thermal expansion of 10.5 ppm/K.

In a further embodiment the glass carrier of the electrical device and in particular of the Rogowski coil may feature a closed path shape like a toroid or a ring. Various shapes of the path are possible such as circular, oval, elliptic, rectangular, or rectangular with rounded ends and/or rounded edges.

The cross section of the carrier can be oval like in Fig. 1, circular like in Fig. 2, or any other suitable shape such as elliptic or rectangular with rounded ends and/or rounded corners. The glass carrier may feature a groove for the return wire which is aimed to make the electrical device and/or the Rogowski coil insensitive to magnetic fields perpendicular to the path of the carrier. The cross-sensitivity would be null or zero if the depth of the groove is such that the return wire passes through the centre of the coil. However, the depth of the groove may be smaller in order to facilitate the fabrication process of the carrier and/or the winding of the core. An example of toroidal carrier provided with a groove for the return wire is shown in Fig. 5, where the groove is applied to the carrier such that two symmetric lobes are obtained. However, other implementations of the groove are possible and the groove may be applied from different directions, may have different profiles, or may have various depths. Such example is shown in Fig. 6.

The path of the glass carrier may also be open, e.g. have one or more gaps, and/or the Rogowski coil and/or electrical device may consist of multiple coils at which the number of coils and their arrangement may vary.

Furthermore the electrical device, in particular a Rogowski coil, may feature either a single layer winding or multiple layers for increased sensitivity. The multiple layers typically feature alternating winding directions in order to make the electrical device insensitive to magnetic fields perpendicular to the path of the carrier.

Besides that the glass carrier may be covered with a thin polymer layer in order to control the friction between the coil wire and the carrier and/or to improve the adhesion of the wire to the carrier.

The electric device, in particular a Rogowski coil, described in this invention can be partly or totally enclosed in an electrical shield in order to protect it from electrical interferences. The electrical shield may be made from one or more pieces of conductive or semi-conductive material, which can be solid or flexible, where typical examples of materials employed are based on metals, plastics loaded with conductive fillers, or plastics covered with one or more metallization layers.

The electric device and/or Rogowski coil can be used for a wide range of currents and various applications like electrical power transmission and distribution, electrical energy metering, AC motor control, or instrumentation. While the present invention originates from the area of current sensors employed in electrical power transmission and distribution, its area of application is much broader.

Moreover, a current sensor comprising an electrical device according to the invention to be employed in electrical power transmission and distribution, in particular in electrical power transmission and distribution stations or switchgears, or in electrical energy metering, is disclosed and claimed and is therefore explicitly included into the claim of the present application and is consequently within the scope and the content of disclosure.

These and further embodiments and improvements of the invention are subject matter of the sub-claims.

By means of an exemplary embodiment shown in the accompanied drawing the invention itself, preferred embodiments and improvements of the invention and specific advantages of the invention shall be explained and illustrated in more detail.

It is shown in

Fig. 1 a glass coil carrier with the shape of a toroid having an oval cross section;

Fig. 2 a glass coil carrier with a toroidal shape having a circular cross section;

Fig. 3 a glass coil carrier with the shape like an elliptic ring where the cross section of the coil may be of any suitable shape;

Fig. 4 a glass coil carrier with the shape like a rectangular ring whereas the rectangular shape has rounded corners and where the cross section of the coil may be of any suitable shape;

Fig. 5 a glass coil carrier with a toroidal shape having a groove for the return wire, applied in the midplane of the carrier;

Fig. 6 a glass coil carrier with a toroidal shape having a groove for the return wire;

Fig. 7 an electrical device according to the invention comprising a glass carrier, a toroidal coil and a return wire, used as a Rogowski coil;

Fig. 8 an electrical device according to the invention comprising an assembly of four coils with straight glass carriers, wherein the coils are uniformly and symmetrically arranged and wherein the assembly is used as a Rogowski coil.

In the following the exemplary embodiments of the invention being displayed in the drawings are described in more detail.

Fig. 1 represents a first embodiment of a glass carrier 10 according to the invention, in particular to be employed in a Rogowski coil, with the form of a toroid having a cross section 12 with the form which can be approximated by an oval or an ellipse. The oval or elliptic cross section 12 is advantageous in some cases because it allows reaching an elongated shape while ensuring good contact between the coil wire and the glass carrier.

In Fig. 2 a second embodiment of a glass carrier 14, in particular to be employed in a Rogowski coil, with the form of a toroid and having a cross section 16 with the form of a circle is shown.

Fig. 3 depicts a third embodiment of a glass carrier 18 according to the invention, in particular to be employed in a Rogowski coil, which has the shape like an elliptic ring. The elliptic or oval ring shape of the carrier 18 may be advantageous for selected measuring applications. The cross section of the carrier 18 is not made visible in this picture and may be of any suitable shape, e.g. circular or oval.

Fig. 4 represents a fourth embodiment of a glass carrier 19, in particular to be employed in a Rogowski coil, with the form of an approximately rectangular ring having rounded corners where the cross section of the carrier may be of any suitable shape, e.g. circular or oval.

In Fig. 5 a glass carrier 20 of a Rogowski coil is shown having a toroidal form, wherein the glass carrier 20 is provided with a groove 22 for the return wire. In this particular example, the groove is applied through the midplane of the carrier such that two symmetric lobes are obtained in the cross-sectional area. The cross section 24 of the glass carrier has the form like an oval with a hollow resulting from the groove 22, the deepest part of the hollow being approximately in centre of the oval.

Fig. 6 shows a different embodiment of a glass carrier 26 with a groove 28 applied perpendicular to the midplane of the carrier. The depth of the groove 28 may take any value between almost zero and up to approximately the midplane of the carrier.

In Fig: 7 an electrical device 30 according to the invention, in particular a Rogowski coil, is shown having a toroidal glass carrier 32 provided with a toroidal coil 34 of electrically conductive wire and /or an electrically conductive wire wound/arranged in a helical manner around the toroidal glass carrier 32. The coil 34 is formed by a plurality of winding turns 35 which are wound around the glass carrier 32 and is provided with a return wire 36 which is placed in a groove of the glass carrier 32, the groove being not visible in this figure. The groove of the glass carrier 32 may be implemented as shown in Fig. 5 or Fig. 6, but other implementations are also possible. The electrical device 30 is provided with electrical terminals 38 for electrical connectivity.

Fig. 8 shows an assembly 40 of at least four identical coils 42, 44, 46, 48 electrically connected in series using conductors 58 where the coils are wound on straight glass carriers 50, 52, 54, 56 and where they are uniformly and symmetrically arranged, e g. at one side of a square,,the assembly of coils 40 being used as a Rogowski coil. The cross section of the carriers 50, 52, 54, 56 may be of any suitable shape, e.g. circular or oval. The assembly of coils 40 is also provided with a return wire 60 and with electrical terminals 62 for electrical connectivity.

Accordingly Fig. 7 and Fig. 8 represent each a tangible electrical device 30, 40 according to the invention, in particular to be used as a Rogowski coil, wherein the electrical device comprises at least one coil 34, 42, 44 of electrically conductive wire wound around a glass carrier and is provided with a return wire 36, 60. The return wire 36, 60 makes the electrical device 30, 40 insensitive to magnetic fields perpendicular to the path of the electrical device 30, 40, however, it may not be required in any application.

Furthermore, as already mentioned above, the dimensions of the coils depend on the respective carriers which are provided as glass carriers since it has been found that glass carriers have excellent dimensional and physical stability, i.e. such carriers keep their dimensions independent from impacts such as temperature expansion, water absorption, or aging.

Hence the subject matter of this invention is directed to the material and its properties being provided for manufacture of carriers for electrical devices, such as coils, in particular for Rogowski coils.

The present invention also comprises any combination of preferred embodiments as well as individual features and developments provided they do not exclude each other.

Reference List

10	first embodiment of a glass carrier
12	oval cross section
14	second embodiment of a glass carrier
16	circular cross section
18	third embodiment of a glass carrier
19	fourth embodiment of a glass carrier
20	fifth embodiment of a glass carrier
22	groove for the return wire
24	oval cross section with hollow resulting from the groove
26	sixth embodiment of a glass carrier
28	groove for the return wire
30	electrical device according to the invention (Rogowski Coil)
32	glass carrier
34	toroidal coil
35	winding turns
36	return wire
38	electrical terminals
40	electrical device according to the invention comprising an assembly of coils
42, 44, 46, 48	coils
50, 52, 54, 56	straight glass carriers
58	conductor
60	return wire
62	electrical terminals

Claims

1. Electrical device (30, 40) for measuring alternating current or current pulses which comprises at least one coil (34, 42) of electrically conductive wire being wound around a non-magnetic carrier (10, 20, 26, 32, 50),
characterized in that
the non-magnetic carrier (10, 20, 26, 32, 50) is made of glass.

2. Device according to claim 1, characterized in that at least one coil of wire (34) being wound around a non-magnetic carrier (10, 14, 20, 26, 32) is formed like a toroid or like an approximately oval or elliptic ring.

3. Device according to claim 1, characterized in that an assembly of at least two coils is provided, wherein the coils (42, 44, 46, 48) being electrically connected in series and wherein each coil (42, 44, 46, 48) is wound on a non-magnetic carrier (50, 52, 54, 56), and wherein the coils (42, 44, 46, 48) are symmetrically arranged such that they form a closed or almost closed loop.

4. Device according to one of the preceding claims 1 to 3, characterized in that, the non-magnetic carrier (10, 20, 26, 32, 50) is made of glass with a low glass transition temperature.

5. Device according to one of the preceding claims 1 to 4, characterized in that the glass transition temperature of the glass material for the non-magnetic carrier (10, 20, 26, 32, 50) is between 200°C and 700°C

6. Device according to one of the preceding claims, characterized in that the non-magnetic carrier (10, 20, 26, 32, 50) is made of silicon dioxide mixed with other ingredients.

7. Device according to claim 6 where the non-magnetic carrier (10, 20, 26, 32, 50) is made of soda-lime glass or borosilicate glass.

8. Device according to one of the preceding claims where the non-magnetic carrier (10, 20, 26, 32, 50) is manufactured employing a glass molding or glass pressing process.

9. Device according to one of the preceding claims 1 to 7, characterized in that the non-magnetic carrier (10, 20, 26, 32, 50) is manufactured employing a precision glass molding process or is made of precision molding glass.

10. Device according to one of the preceding claims, characterized in that a return wire (36, 60) is lead from one end of the coil (34) or assembly of coils (40) to the other end of the coil (34) or assembly of coils (40), so that both wire terminals are at the same end of the coil (34) or assembly of coils (40).

11. Device according to one of the preceding claims, characterized in that a groove (22, 28) is provided in the non-magnetic carrier (20, 26, 32) such that the return wire (36) can be located in the groove (22, 28).

12. Device according to claim 11, characterized in that the groove (22, 28) passes trough the centre or close to the centre or centre axis of the coil (34).

13. Device according to one of the preceding claims, characterized in that the non-magnetic carrier (10, 20, 26, 32, 50) is covered with a polymer layer.

14. Device according to one of the preceding claims, characterized in that the electrical coil (34) or assembly of coils (40) is partly or totally enclosed in an electrical shield which comprises one or more pieces of conductive or semi-conductive material.

15. Device according to claim 14, characterized in that the electrical shield comprises or consists of metal, plastic loaded with conductive fillers, or plastic covered with one or more metallization layers.

16. Current sensor comprising an electrical device (30, 40) according to any of the preceding claims to be employed in electrical power transmission and distribution or in electrical energy metering.

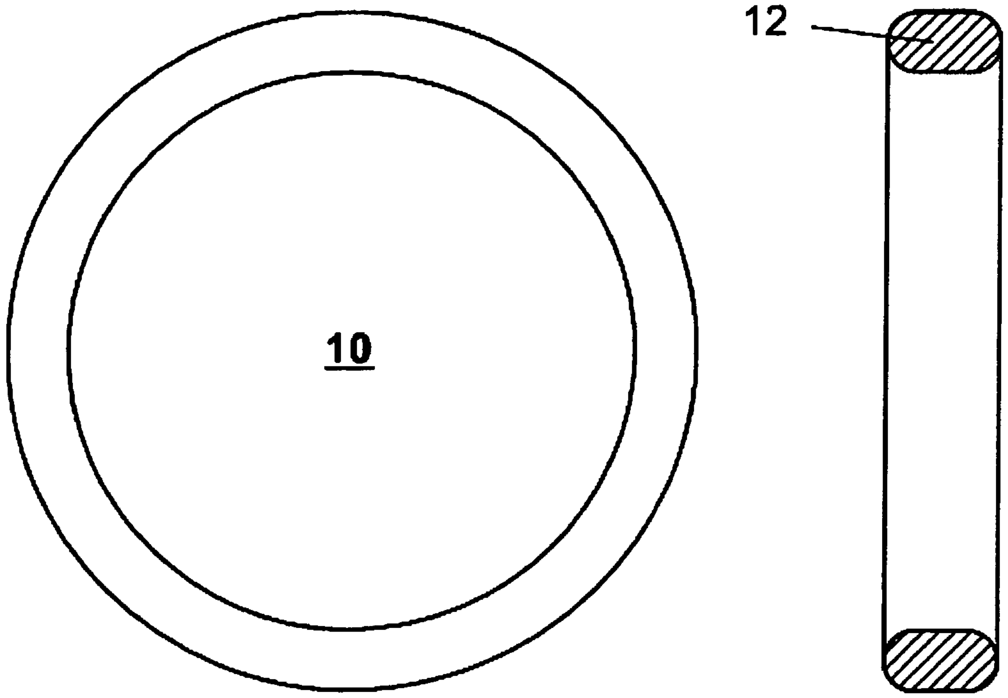

Fig. 1

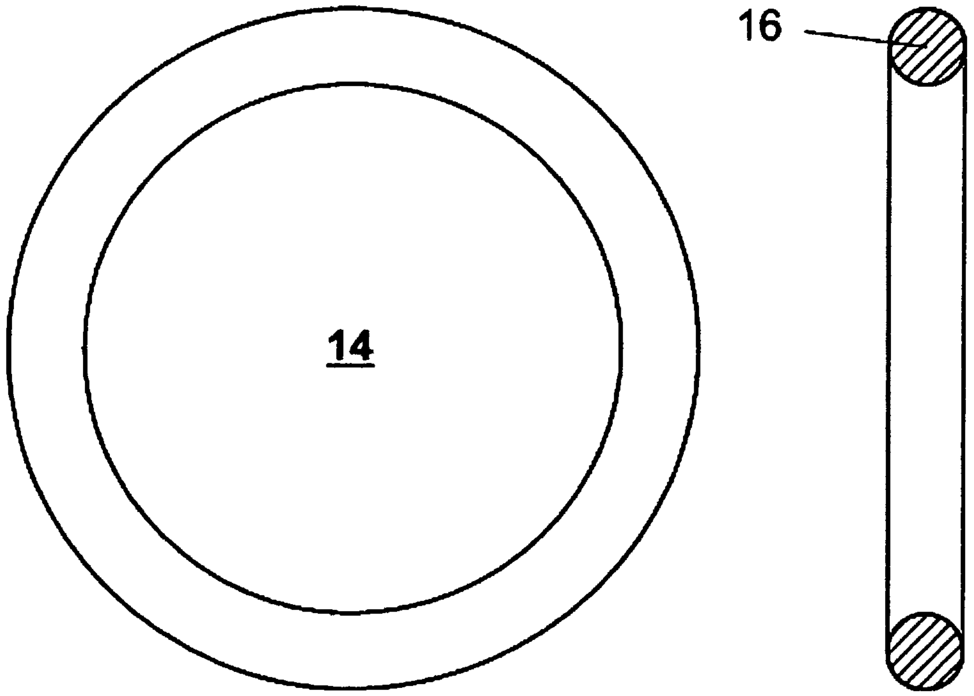

Fig. 2

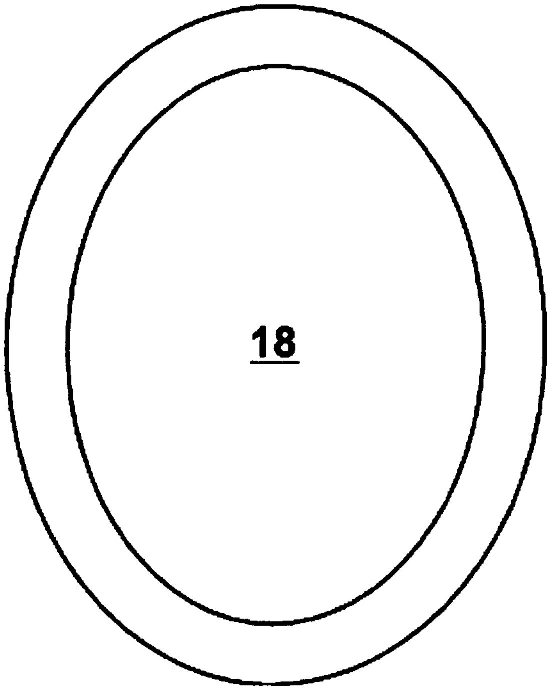

Fig. 3

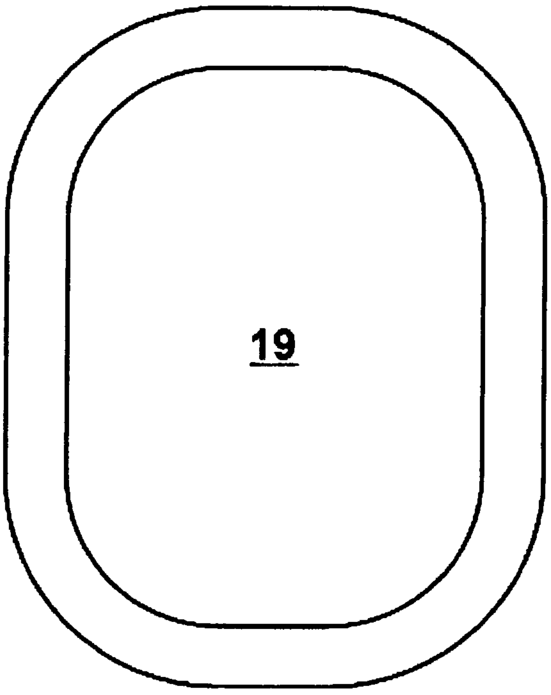

Fig. 4

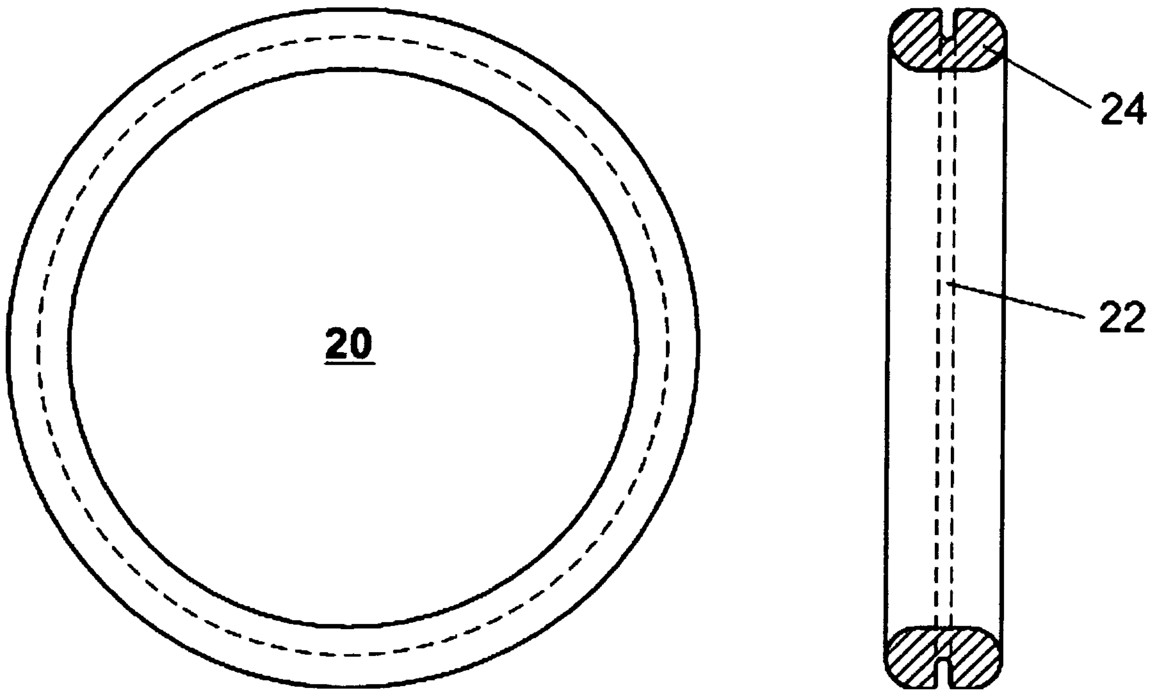

Fig. 5

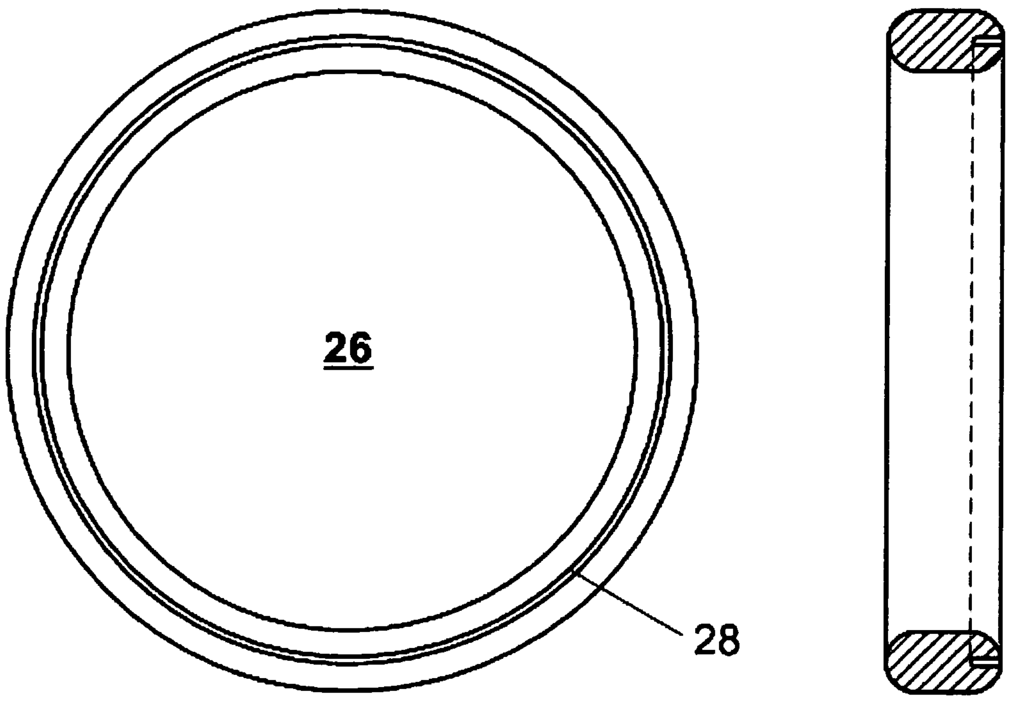

Fig. 6

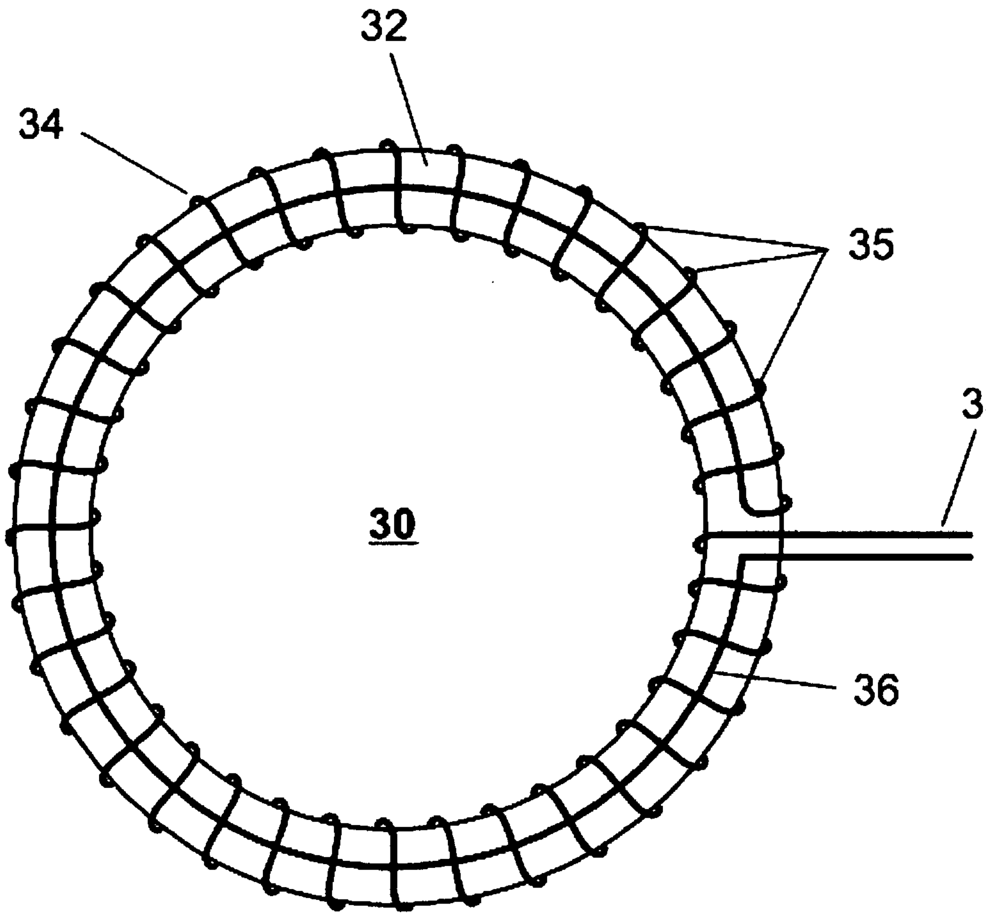

Fig. 7

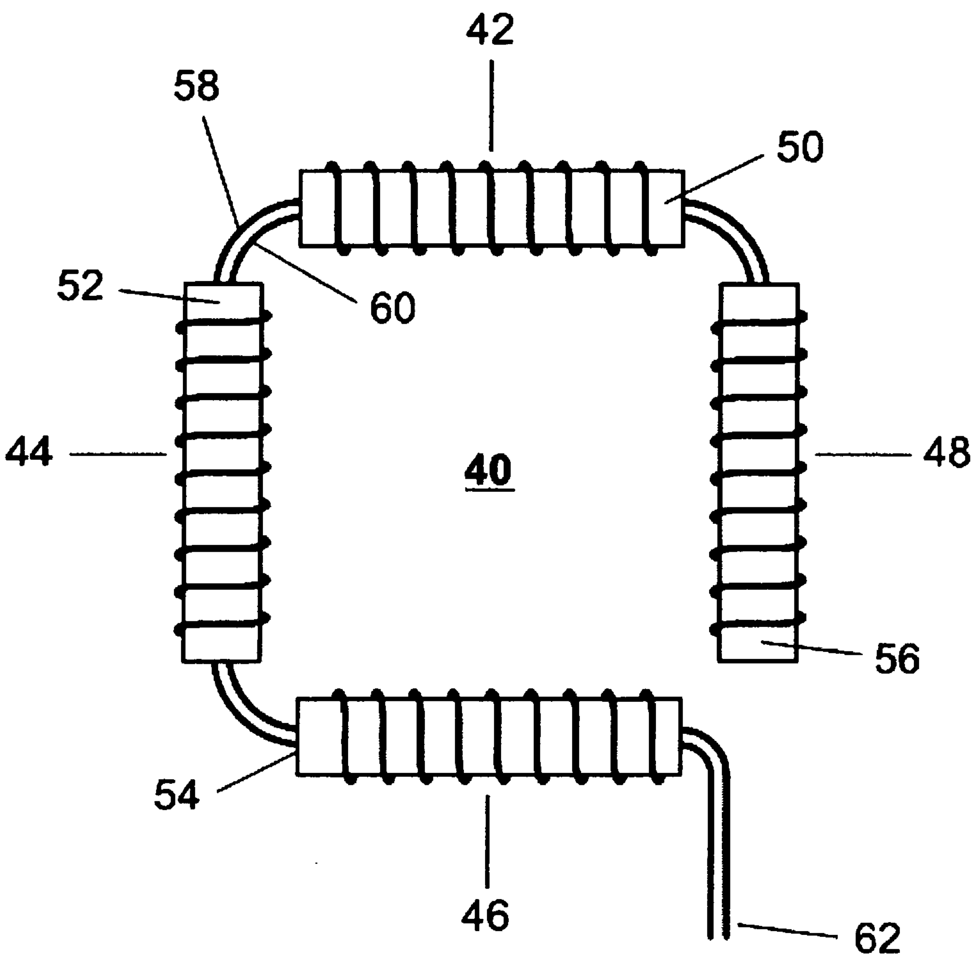

Fig. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/001362

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01F5/02 G01R15/18
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01F G01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005/156587 A1 (YAKYMYSHYN CHRISTOPHER P [US] ET AL YAKYMYSHYN CHRISTOPHER PAUL [US] E) 21 July 2005 (2005-07-21) abstract; claims 1-42; figures 1A-9 paragraph [0026] - paragraph [0046] paragraph [0069] - paragraph [0070] -----	1-16
A	US 2009/052214 A1 (EDO MASAHARU [JP] ET AL) 26 February 2009 (2009-02-26) abstract; claims 1-8; figures 1-16H paragraph [0073] - paragraph [0087] paragraph [0104] - paragraph [0161] -----	1-16
A	JP 2005 310959 A (MURATA MANUFACTURING CO) 4 November 2005 (2005-11-04) abstract; figures 1-6 -----	1-16
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
18 July 2012	25/07/2012

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1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2006/176140 A1 (SKENDZIC VESELIN [US] ET AL) 10 August 2006 (2006-08-10) abstract; claims 1-47; figures 1-8 paragraph [0011] - paragraph [0012] paragraph [0023] - paragraph [0049] -----	1-16

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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