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(54) Title: PARTIAL DISCHARGE SENSOR

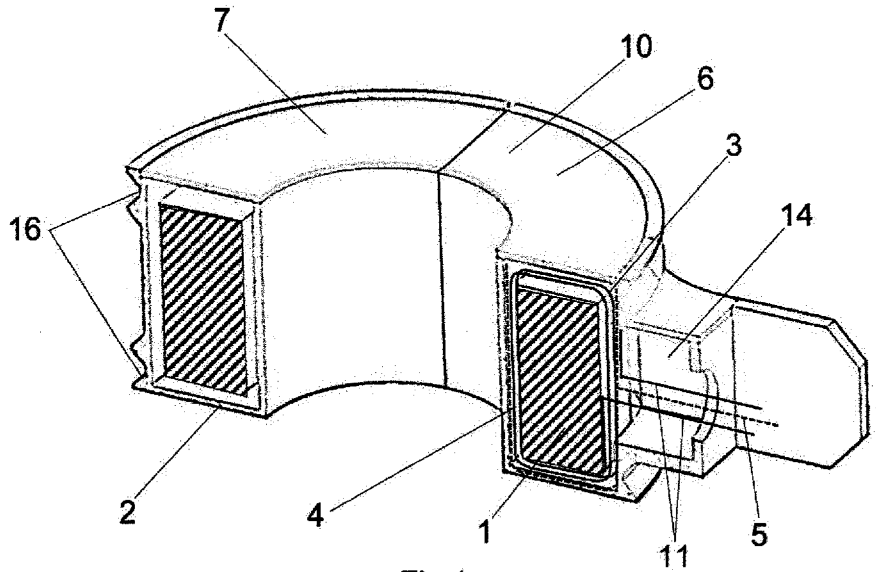

Fig.1

(57) Abstract: A partial discharge sensor, specifically a broadband current inductive partial discharge signal sensor (10) comprising a magnetic core (1) housed in a casing (2) and at least one, arranged on the magnetic core (1), secondary circuit (3), with the magnetic core (1) being made of an amorphous magnetic material, with there being mounted on the magnetic core (1) a maximum of 10 threads (4) of one secondary circuit (3).

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Partial discharge sensor

Technical Field

The invention relates to a partial discharge sensor, specifically to a broadband current inductive partial discharge signal sensor.

State of the Art

The good condition of the insulation of electrical circuits is a basic condition for their proper function. The condition of the insulation is threatened by various factors, such as chemical, electrical or production imperfections. The end state of the insulation is an electric field breakdown and this breakdown is always built up of partial discharges, no matter what impairment of the state of the insulation is created by whichever degradation mechanism, for example degradation of the insulation due to inhomogeneities in production of the insulation, the formation of so-called cavities.

As the electric field approaches, due to polarisation, a positive charge accumulates on one side of the cavity and a negative charge accumulates on the other side. The value of these small charges increases until the moment when the resulting electric potential crosses the insulation barrier and the charges equalise. At that moment, a small discharge is generated, and since the flow of the balancing current stops after the charges have equalised, these discharges are referred to as partial discharges. The resulting flowing stream has several wholly unique properties that occur nowhere else. The balance of charges is not limited by anything, and so an extremely sharp and very short-lasting electrical impulse is generated. It is so unique that it can be likened to the theoretical impulse defined as a Dirac impulse, which is characterised by extreme sharpness and its frequency response is constant across all frequency bands.

This property is the basic approach to differentiate from other sources of interference and to detect partial discharges. Due to its similarity to Dirac's discharge, the partial discharge behaves very similarly, spreading over all frequency bands, with the only deviation being that with increasing frequency value there is a slight attenuation of this value.

At present, a large number of patent-protected technical solutions dealing with the issue of partial discharges are known.

Devices are known which solve the measurement of partial discharges by very classical instruments, such as a spectrum analyser or an oscilloscope. Furthermore, sensors for sensing partial discharges are known, which are physically two types, namely, voltage sensors for partial discharges and current sensors for partial discharges.

From utility model CZ 25229 is known the use of a detector for evaluating the probability of the occurrence of partial discharges in the body of an encased transformer, which extends into the inner space of the transformer and which consists of an antenna and is connected to a measuring device. The detector has an antenna provided with a reflector which is joined to the antenna power connector, with at least one detector being located on the transformer housing and extending inside the transformer via the non-metallic design of the bushing housing. The disadvantage of this sensor is that it can only be used with a transformer, it cannot be used anywhere else for other sources of discharges.

From patent document CZ 284557 is known a meter which consists of a load impedance and a broadband or narrowband amplifier, evaluation circuits connected to the amplifier output, and control and synchronisation units, or a display at the output of the evaluation circuits. Evaluation circuits connected to the output of a broadband or narrowband amplifier consist of a charge converter for time, the output of which is connected to the input of the time converter of the converted charge and to the input of the counter defining the position of that impulse on the basic measuring voltage period, where the outputs of these counters are connected to the memory, which is further connected to the indication circuits. To the output of the time charge converter can also be connected the sum of all times of partially discharged charges during the measuring voltage period, its output being connected to the memory and/or a counter of the number of partial discharge impulses in the measured period, the output of which is connected to the memory.

A partial discharge sensor is furthermore known from patent document US20080174320, which comprises a primary current transformer having an opening. Inside the opening of the primary current sensor and close to it is located a conductive shield. The concentric openings of the primary current sensor and the conductive shield are arranged to receive the first high voltage power conductor. The second conductor is electrically connected to the conductive shield. The second conductor is structured to be electrically connected to ground. The second sensor interacts with the second conductor and is structured to sense signals associated with partial discharge activity. The output of the second sensor is received by an electronic monitoring circuit. The electronic monitoring circuit is arranged to provide on-line monitoring of the partial discharges occurring in the primary high voltage power conductor. The disadvantage of this sensor is its complex construction, very complicated assembly and above all its lower sensing sensitivity.

From the above-mentioned currently known technology, it is clear that most devices for sensing partial discharges are structurally very complex and, in view of this, are essentially stationary without the possibility of their simple assembly and simple disassembly from the monitoring area.

The object of the invention is a simple and variable construction of a broadband current inductive sensor with a very wide frequency range, which will be able to capture a partial discharge.

Principle of the Invention

The mentioned disadvantages are largely eliminated and the goal of the invention fulfilled by a partial discharge sensor, specifically a broadband current inductive partial discharge signal sensor, comprising a magnetic core housed in a casing and at least one secondary circuit arranged on the magnetic core, characterised by that the magnetic core is made of an amorphous magnetic material, with there being a maximum of 10 threads of one secondary circuit mounted on the magnetic core. The advantage is that the partial discharge sensor allows monitoring with a high frequency range. Another advantage is the very high permeability of the magnetic core. Another great advantage is that, thanks to the material used, various sensor sizes can be assembled without limiting their functionality. The value of the secondary winding is a maximum of 10 threads and thus the optimal inductance is set, guaranteeing a very small to negligible effect on the shape of the transmitted impulse, which means maintaining the steepness of the sensed partial discharge. The advantage of this arrangement is simple production without the need for special winding machines.

It is to further advantage if the secondary circuit is provided with a shield. If the secondary circuit were not shielded and the shield not grounded, ambient interference could begin to be induced in the secondary circuit because the unshielded secondary circuit can act as a receiving antenna for surrounding interference. Although the sensor itself is relatively resistant to undesirable noise phenomena, the use of shielding further significantly increases this resistance.

It is also to advantage if the casing with the magnetic core is designed to be transversely divided into two parts. The magnetic core with the casing are split in half. One part consisting of half of the magnetic circuit with a secondary winding and a joining connector, the other part the remaining core with a casing. This is to great advantage because the measured conductor passes through the inside of the current sensor, so that the measured conductor does not have to disconnect during mounting of the sensor. Another advantage is the small construction volume required, which is very important in newly installed transformer stations, where there is already very little space.

At the same time, it is also to advantage if the casing is provided with at least two insertion pins which are arranged within the casing. The advantage is that the two halves are easily fit together by means of the insertion pins in the protrusions of the side walls of the sensor casing, which results in a very simple and undemanding assembly and thus to a reduction in costs.

The secondary circuit is to advantage joined to the connector via terminals. The advantage is that during production it is not necessary to create sensors with a terminal, but according to needs, more precisely according to the location of the sensor, the supply wires can be made to measure thanks to the connector joining.

It is also to advantage if the casing is provided with a connector chamber. The advantage is the simplification of the assembly of the connector, where the conductors have a winding space apart from the threads, where they are folded up in after attaching the conductors to the connector.

The housing is preferably made of a self-extinguishing material, which is to greatest advantage polyethylene terephthalate glycol (PETG).

To advantage, the magnetic core is designed as toroidal. The advantage is that the toroidal core has excellent magnetic properties, above all very low magnetic losses and high resistance to external magnetic fields, while it can be easily mechanically adjusted, for easy assembly, during production and end use as well.

It is to further advantage if the magnetic core is made of an amorphous magnetic material, which is wound with nanoplate of a thickness of about 10μm. Thanks to its very fine structure, the wound nanoplate has very favourable frequency parameters, from 0 Hz to 2 MHz. The advantage is that the use of nanoplates significantly amplifies the signal, which is excited by only the small primary current generated by the current of the partial discharge.

It is also to advantage if the magnetic core is made of an amorphous Fe-based magnetic material. The advantage is the excellent magnetic properties of such a material.

To advantage, a resin is arranged in the free space in the cavity of the magnetic core casing.

It is to great advantage if the casing is provided on its surface with at least one cable tie, which holds the two halves of the housing together simply in such a way that the sensor performs its function safely and securely. The advantage of this solution is its cost-effectiveness.

The main advantage of the partial discharge sensor according to the invention is that it allows monitoring with a high frequency range. It is also to advantage that the use of nanoplates significantly amplifies the signal, which is excited by only the small primary current generated by the current of the partial discharge. Due to the small number of threads of the primary and secondary windings, the intrinsic inductance of the entire magnetic circuit is very small (approx. <30μH). As a result, this does not affect the course of the primary current impulse and is transmitted very faithfully to the secondary side. Thanks to the divided design, the sensor can be easily mounted on the measured conductor. It is divided transversely into two halves, which fit together and encircle the measured conductor and secure against its own decomposition and spontaneous displacement. A great advantage is also the resistance to external interference and thus its usability in circuits, which is characterised by high selectivity of the received signals. Very simple assembly and low purchase price are also great advantages. The sensor is primarily intended for sensing partial discharges in high voltage cables, where the discharge activity is mainly related to shielding braiding, which is used in all modern HV cables. Since this shield is grounded at the starting points of the cable ends, a current impulse from a specific discharge in a particular monitored cable passes through a grounding connection to ground. Because there is very little space in modern substations, it is very advantageous to use an inductive sensor, due to its small size (ø 80 x 30mm), which allows one to read information about partial discharges of the monitored device from the grounding conductor, which is connected from the cable to the grounding network of the object. There is no need to connect directly to the voltage supply level with a voltage sensor, which is usually of much larger dimensions (eg ø 200 x 380 mm) and mass. This leads to a very significant saving of space, and this inductive sensor can be placed into all substations without complications and restrictions.

Overview of the Figures

The invention will be further elucidated using drawings, in which fig.1 shows a cross-sectional perspective view of the arrangement of individual parts of the sensor, fig. 2 shows a frontal view of the sensor ready for mounting at the measuring point, fig. 3 shows a perspective view of the whole sensor, fig. 4 shows a circuit diagram of the individual parts of the sensor, and fig. 5 shows a perspective view of the partial discharge sensor installed on a conductor.

Examples of the Performance of the Invention

The broadband current inductive sensor 10 of the partial discharge signal (fig.1, fig. 2, fig. 3, fig. 4, fig. 5) comprises a magnetic core 1 housed in a casing 2 and on the magnetic core 1 a secondary circuit 3 is mounted.

The magnetic core 1 is made of an amorphous magnetic material.

On the magnetic core 1 a maximum of 10 threads 4 of the secondary circuit 3 are mounted. Alternatively, on the magnetic core 1 4 threads 4 of the secondary circuit 3 can be mounted.

The secondary circuit 3 is provided with a shield 5.

The casing 2 with the magnetic core 1 is designed as transversely divided into two parts 6,7, the casing 2 being provided with four insertion pins 8, which are arranged in the fitting 9 of the casing 2.

The secondary circuit 3 is joined via terminals 11 to a connector 12, which is connectable by a cable 13 to an external computer evaluation device. The connector 11 has IP 68 protection.

The casing 2 is provided with a chamber 14 of the connector 12, being made of a self-extinguishing material which is polyethylene terephthalate glycol (PETG).

The magnetic core 1 is made to be toroidal from an amorphous magnetic material, which is a wound nanoplate.

The magnetic core 1 is made of an amorphous magnetic material based on Fe, which amorphous material can be any of the materials listed in the following table:

Substance	Fe % by mass	Ni % by mass	Co % by mass	Cu % by mass	Nb % by mass	Si % by mass	B % by mass
1	66,4	11,6	8,1	1,0	5,3	5,9	1,7
2	74,2	11,6	0	1,0	5,3	6,2	1,7
3	79,7	5,8	0	1,0	5,4	6,4	1,7
4	84,5	0	0	1,8	5,2	7,6	1,7
5	82,8	0	0	1,3	5,6	8,8	1,5

The casing 2 with the magnetic core 1 contains a free space in which a resin is arranged.

The casing 2 is provided on its surface with two cable ties 15, which are arranged in the end grooves 16 of the casing 15.

The partial discharge sensor 10 operates in such a way that the current flowing through the primary conductor 17 generates an electromagnetic field which induces a magnetic flux in the magnetic circuit. This magnetic flux in the magnetic core 1 in the secondary circuit 3 induces a voltage which is an image of the primary current and its parameters of are transmitted for further processing by an external evaluation computer device to determine the presence of a partial discharge.

Industrial Application

The partial discharge sensor according to the invention can specifically be used to detect partial discharges in high-voltage cables.

List of Reference Marks

1 magnetic core
2 casing
3 secondary circuit
4 thread
5 shielding
6 part I
7 part II
8 insertion pin
9 casing fitting
10 sensor
11 outlet
12 connector
13 cable
14 chamber
15 cable tie
16 groove
17 primary conductor

Patent Claims

1. A partial discharge sensor, specifically a broadband current inductive partial discharge signal sensor (10) comprising a magnetic core (1) housed in a casing (2) and at least one, arranged on the magnetic core (1), secondary circuit (3), **characterised by that** the magnetic core (1) is made of an amorphous magnetic material, and there being mounted on the magnetic core (1) a maximum of 10 threads (4) of one secondary circuit (3).
2. The partial discharge sensor according to claim 1, **characterised by that** the secondary circuit (3) is provided with a shield (5).
3. The partial discharge sensor according to either one of claims 1 and 2, **characterised by that** the casing (2) with the magnetic core (1) is designed to be transversely divided into two parts (6,7).
4. The partial discharge sensor according to claim 3, **characterised by that** the casing (2) is provided with at least two insertion pins (8) which are arranged within the fitting (9) of the casing (2).
5. The partial discharge sensor according to any one of claims 1 to 4, **characterised by that** the secondary circuit (3) is, via terminals (11), joined to the connector (12).
6. The partial discharge sensor according to any one of claims 1 to 5, **characterised by that** the casing (2) is provided with a chamber (14) of the connector (12).
7. The partial discharge sensor according to any one of claims 1 to 6, **characterised by that** the casing (2) is made of a self-extinguishing material.
8. The partial discharge sensor according to any one of claims 1 to 7, **characterised by that** the housing (2) is made of a self-extinguishing material which is polyethylene terephthalate glycol.
9. The partial discharge sensor according to any one of claims 1 to 8, **characterised by that** the magnetic core (1) is designed to be toroidal.
10. The partial discharge sensor according to any one of claims 1 to 9, **characterised by that** the magnetic core (1) is made of an amorphous magnetic material, which is a wound nanoplate.
11. The partial discharge sensor according to any one of claims 1 to 10, **characterised by that** the magnetic core (1) is made of an amorphous magnetic material based on Fe.

12. The partial discharge sensor according to any one of claims 1 to 11, **characterised by that** the casing (2) with the magnetic core (1) has a free space in which a resin is arranged.
13. The partial discharge sensor according to any one of claims 1 to 12, **characterised by that** the casing (2) is provided on its surface with at least one cable tie (15).

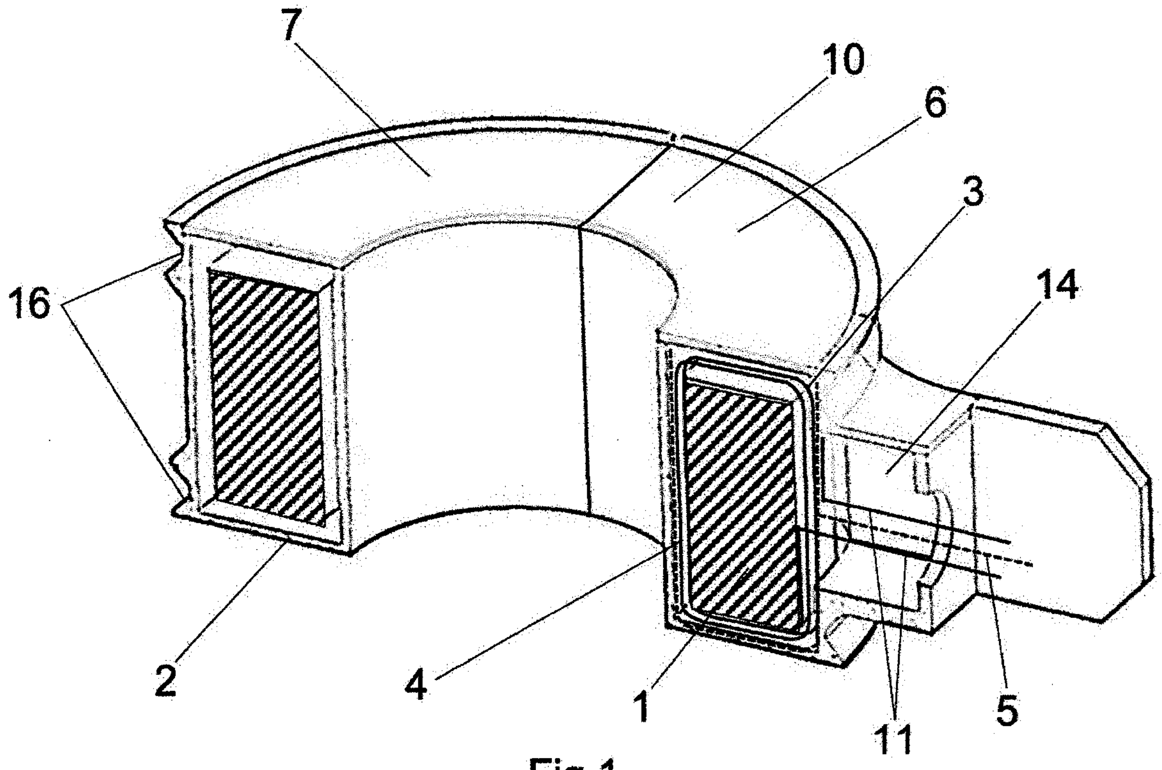

Fig.1

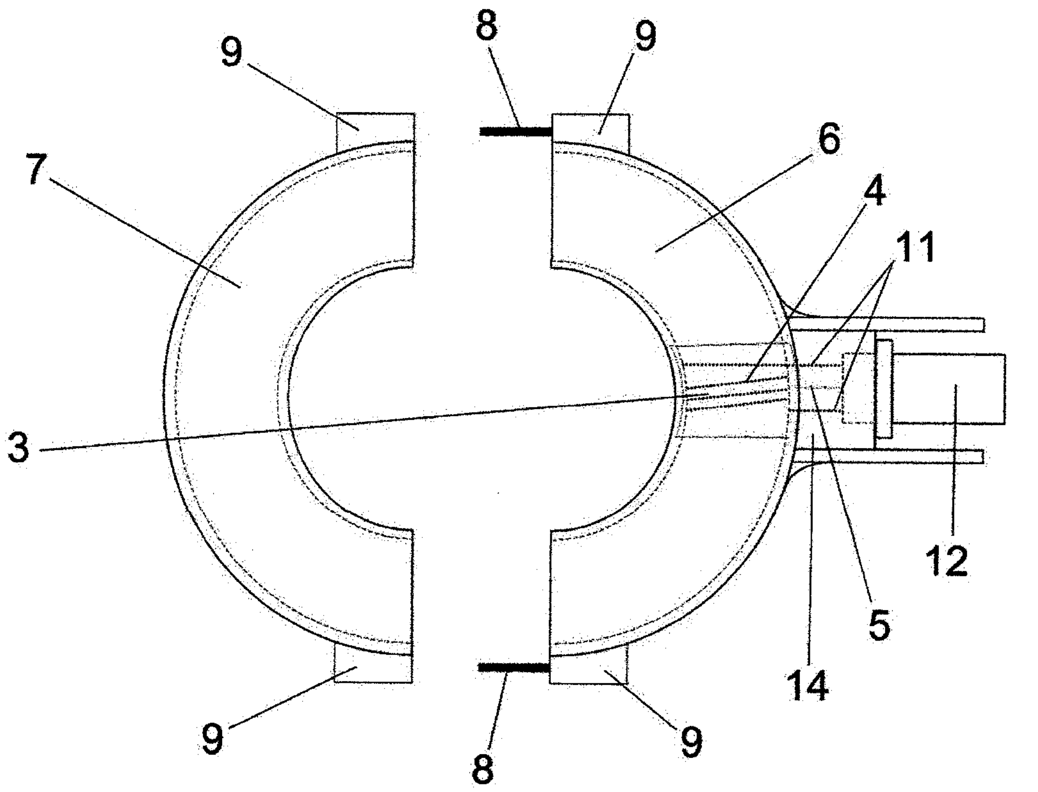

Fig.2

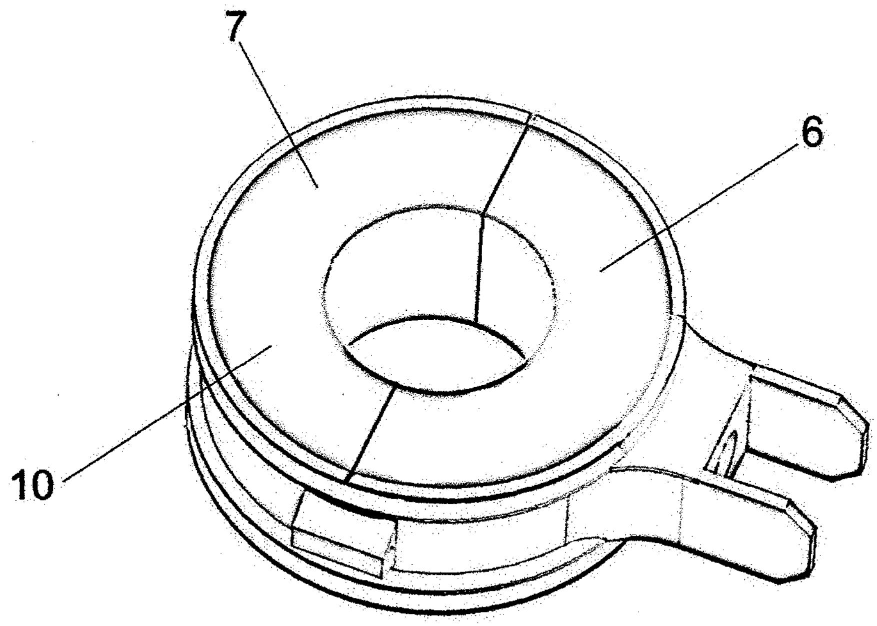

Fig.3

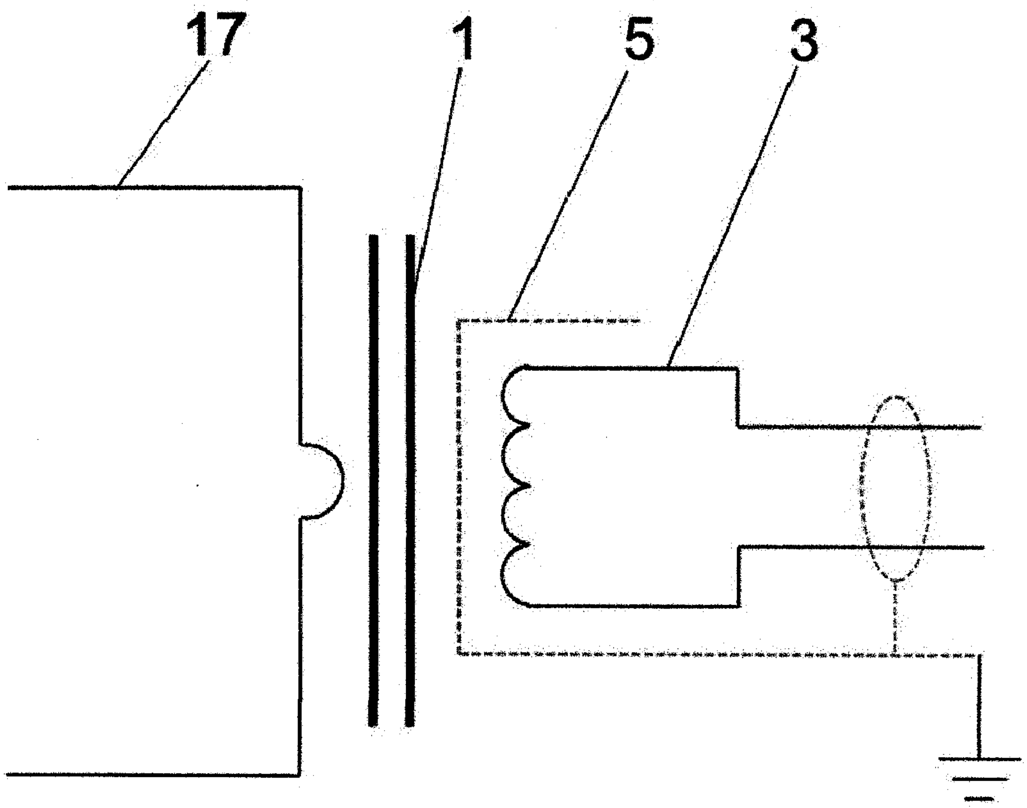

Fig.4

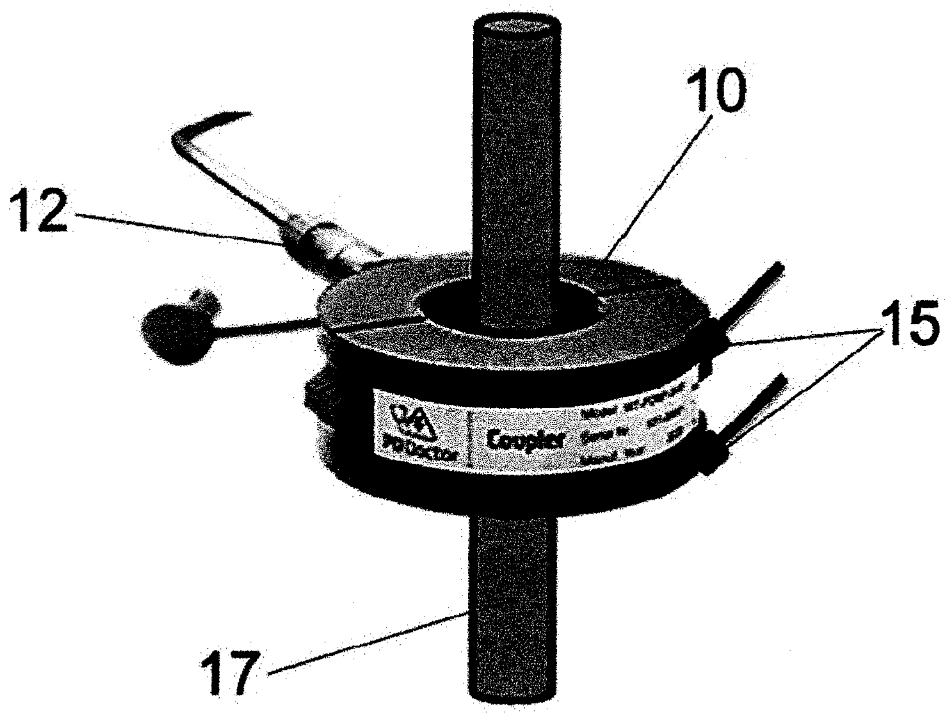

Fig.5

INTERNATIONAL SEARCH REPORT

International application No
PCT/CZ2022/000005

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01R15/18 G01R31/12
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)
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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 929 903 A (SAIGO AKIRA [JP] ET AL) 29 May 1990 (1990-05-29) column 8, line 59 - column 11, line 27; figures 8A, 8B -----	1-13
A	US 2019/128927 A1 (SHAW STEVEN A [US] ET AL) 2 May 2019 (2019-05-02) paragraph [0012]; figure 1 -----	1-13
A	KR 102 195 478 B1 (J&D ELECTRONICS CO LTD [KR]) 29 December 2020 (2020-12-29) the whole document -----	1-13
A	US 3 684 955 A (ADAMS DUANE J) 15 August 1972 (1972-08-15) the whole document -----	1-13

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"P" document published prior to the international filing date but later than the priority date claimed

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Date of the actual completion of the international search	Date of mailing of the international search report
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Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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