(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
15 October 2020 (15.10.2020)

WIPO | PCT

(10) International Publication Number
WO 2020/208471 A1

(51) International Patent Classification:
G01N 33/38 (2006.01) *G01N 27/04* (2006.01)

(21) International Application Number:
PCT/IB2020/053056

(22) International Filing Date:
31 March 2020 (31.03.2020)

(25) Filing Language: Italian

(26) Publication Language: English

(30) Priority Data:
102019000005452 09 April 2019 (09.04.2019) IT

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *of inventorship (Rule 4.17(iv))*

(54) Title: SYSTEM FOR MEASURING THE ELECTRICAL RESISTIVITY OF CONCRETE, AT DIFFERENT DEPTHS, IN NEW AND EXISTING STRUCTURES

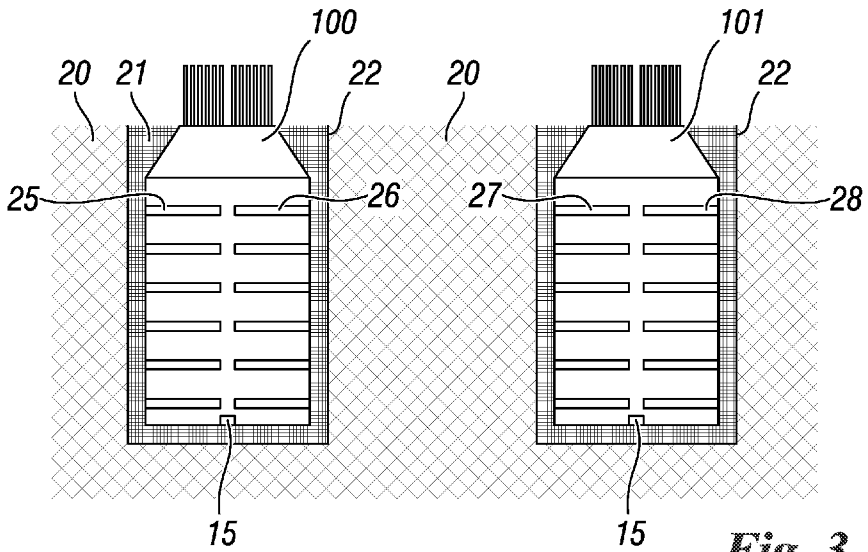

Fig. 3

(57) Abstract: A System for measuring the electrical resistivity of concrete in already existing constructions comprising a first probe and a second probe placed in two separate holes of a construction; said first and second probes comprise: a tubular element (10); a first electrode (11) and a second electrode (12), placed at the same height so as to form a pair of electrodes (11, 12) electrically isolated from one another by means of the interposition of an insulating material (14); a plurality of said pair of electrodes (11, 12) are placed on said tubular element (10) at different heights.

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Published:

— *with international search report (Art. 21(3))*

— *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

"SYSTEM FOR MEASURING THE ELECTRICAL RESISTIVITY OF CONCRETE, AT DIFFERENT DEPTHS, IN NEW AND EXISTING STRUCTURES"

DESCRIPTION

The present invention relates to a system for measuring the electrical resistivity of concrete and to a method for measuring the electrical resistivity of concrete in particular in existing structures.

The deterioration of concrete influences the durability of structures, affecting their functionality and safety; in particular due to the corrosion of the reinforcements.

Initially, concrete has a highly alkaline solution (pH~13) on the inside thereof, in this condition, there is the formation of a protective layer of oxides on the reinforcement bars that prevent the corrosion thereof. Over time, however, this protection diminishes. One of the causes that most frequently lead to the loss of protection, and therefore to the possible corrosion of the reinforcements, is the carbonation of concrete. This is caused by the reaction of carbon dioxide present in the atmosphere with the alkaline constituents of concrete. There is therefore a decrease in the pH of concrete to near-neutral values. Carbonation penetrates the concrete and when it reaches the surface of the reinforcements, it causes the destruction of the protective film; in these conditions, in the presence of water and oxygen, the bars corrode. The corrosion rate of the reinforcements provided in existing structures is not easy to determine.

The measurement of the electrical resistivity of concrete is one of the methods for obtaining an estimate of the corrosion rate of the reinforcements.

Probes are known which allow to carry out measurements of electrical resistivity at different depths but the precision is limited and, in particular, when used in an existing structure, the measured electrical resistivity is more representative of the cement grout used rather than the electrical resistivity of the concrete. An example of said probes is a humidity sensor marketed by Sensortec GmbH.

Other examples of probes are found in the documents EP3236258, CN107860977, WO2015/150463, CN207557160, ES2593960, CN108956684.

The object of the present invention is to provide a system for measuring the electrical resistivity of the concrete which overcomes the limitations of the systems proposed in the prior art.

Another object of the present invention is to provide a system which allows to obtain particularly precise measurements.

A further object of the present invention is to provide a system that effectively allows the resistivity of the concrete to be measured in the case of existing structures.

According to the present invention, these objects and others still are achieved by a system for measuring the electrical resistivity of concrete in already existing constructions comprising a first probe and a second probe placed in two separate holes of a construction. Said first and second probes comprise: a tubular element; a first electrode and a second electrode, placed at the same height to form a pair of electrodes electrically isolated from one another by interposing an insulating material; a plurality of said pair of electrodes are placed on said tubular element at different heights.

Said objects are also achieved by a method for measuring the electrical resistivity in concrete in already existing constructions characterized by using a first probe and a second probe, according to claim 1, placed side-by-side and each surrounded by grout, characterized by comprising the steps of: measuring the resistivity between two electrodes placed at a same height as said first probe and providing a first resistivity value; measuring the resistivity between an electrode of said first probe and an electrode of said second probe placed at the same height and providing a second resistivity value; calculating said electrical resistivity in the concrete by eliminating the resistivity of said grout.

Further characteristics of the invention are described in the dependent claims.

The advantages of this solution compared to the solutions of the known art are many.

Thanks to the probe of the present invention, electrical resistivity measurements can be carried out in the material at different depths, as well as, preferably, the measurement of the temperature of concrete.

The probe has the ability to perform the measurement of electrical resistivity, in a homogeneous material (concrete, mortar, etc.), at a specific depth with high resolution, due to the proposed specific geometry.

It allows to measure the electrical resistivity of concrete even in existing structures. In this case, two probes must be used that must be inserted inside two side-by-side holes, made in the structure, at a distance that depends on the maximum diameter of the aggregate used in the concrete (so that the aggregate does not prevent the measurement in the concrete). The probes are fixed by means of a cement grout (with offset withdrawal). Thanks to the characteristics of this new probe, the effects related to the presence of the cement grout on the measurement of the electrical resistivity of concrete can be assessed and, if necessary, eliminated (for example if the resistance of the grout differs from that of concrete).

The probe allows to obtain the resistivity at a precise depth, unlike the known art, which allows to obtain the measurement only vertically between the electrodes provided at two different depths.

The characteristics and advantages of the present invention will become clear from the following detailed description of a practical embodiment thereof, illustrated by way of non-limiting example in the accompanying drawings, wherein:

Figure 1a schematically shows, in a side view, a probe for measuring the electrical resistivity of concrete, and Figure 1b schematically shows, in a top section view, a probe for measuring the electrical resistivity of concrete, according to the present invention;

Figure 2 schematically shows, in a side section view, a probe for measuring the electrical resistivity of concrete, according to the present invention;

Figure 3 schematically shows a pair of probes for measuring the electrical resistivity of concrete in an already existing construction, according to the present invention;

Figure 4 shows the variation of the electrical resistivity, obtained with numerical simulations, as a function of the penetration of a simulated waterfront and the way the measurement is carried out, according to the present invention;

Figure 5 shows the trend of electrical resistivity, measured both with a pre-installed probe (curve b), and with post-installed probes (curve a), and the corrosion rate (curve c) during the advancement of the waterfront from the surface of concrete towards the reinforcement, according to the present invention.

Referring to the attached Figures, a probe for measuring the electrical resistivity of concrete, according to the present invention, comprises a tubular element 10, which forms the probe, initially hollow on which several electrodes 11 and 12 are placed, each in the shape of a half-ring. At the same height two electrodes 11 and 12 are present, opposed to one another to form a pair of electrodes. Different pairs of electrodes 11 and 12 are arranged on the tubular element 10 at different heights.

Each electrode 11 and 12 must be connected to a respective electric cable 13, in the concave rear part, so that it can pass inside the tubular element 10 and come out from above.

The cables 13 are to be connected to a measuring device not shown.

Each pair of electrodes 11 and 12, placed at the same height, therefore has only two spaces 14, which divide one half-ring from the other half-ring, arranged at 180° from one another, between which the measurement is carried out.

The tubular element 10 can preferably comprise a temperature sensor 15 placed in its distal point. In this way, it is also possible to measure the internal temperature of the concrete by connecting the sensor to a measuring instrument.

The measuring device can carry out resistance measurements between each pair of electrodes 11 and 12 both placed at the same height (horizontal measurement) and between each pair of electrodes placed at different heights (vertical measurement).

By knowing the distance between the electrodes and the surface of the electrodes, it is possible to trace the resistivity (Ω•m).

The electrodes 11 and 12 must be conductive and must be resistant to deterioration; they can be made, for example, by using AISI 316 stainless steel.

The electrodes 11 and 12 must be electrically isolated from one another, both horizontally and vertically, therefore the tubular element 10 must be made with a material that has the function of electrical insulation, it must not absorb water and must resist high alkalinity of concrete; it can be made, for example, with a polymer such as PVC or with an epoxy resin.

The tubular element 10 has grooves in which the electrodes 11 and 12 are inserted, and are fixed by gluing or heat welding or other means, so that the diameter of the tubular element is constant and the external profile has no embosses, in order to facilitate the introduction of the same into a hole made in the concrete

The tubular element 10 can be made by moulding or tubes can be used on which material is removed and the grooves are provided to house the electrodes.

When all the electrodes are placed in their housings with the respective cables, the inside of the tubular element 10 is filled with a resin (for example epoxy resin) which must be insulating, must not absorb water and must resist the high alkalinity of concrete.

In an example of embodiment of the probe, it has a diameter of 20 mm, six pairs of electrodes 11 and 12 are provided, placed vertically every 5 mm and each pair 11 and 12 is spaced (width of the opening 14) by 2 mm. To obtain better precision, the opening 14 must be less than 5 mm.

The number of electrodes can vary according to the depth needed to be verified and the spacing between the electrodes, considering that it depends on how much the resolution of the analysis (by reducing the distance between the electrodes the resolution increases) is to be increased.

The electrodes 11 and 12 are made in the shape of a half-ring for ease of production and mounting and to have a surface with large dimension, but alternatively the electrodes 11 and 12 can have other shapes e.g. they can be made by using two conductors (with a circular section or another section) passing inside the tubular element 10 until it comes out onto the surface (on one side or on both sides) of the same and can guarantee contact with the surrounding concrete.

By applying a meter to the various pairs of electrodes 11 and 12, it is possible to measure the resistance at a given height, then carry out a measurement (horizontal) by using two electrodes opposite one another, or a measurement (vertical) between two electrodes placed at different heights can be made.

The single probe 10 can be used to obtain measurements on a homogeneous material, that is, in a new concrete structure or in a material used for restoration; in this case the reduced distance between the half-rings, horizontally, allows to measure the electrical resistivity of the concrete at a specific depth with high resolution. The results obtained with the numerical simulations have, in fact, shown that the precision of the measurement increases as the distance between the electrodes of the half-rings placed at the same depth decreases and as the thickness of the electrodes decreases. It is also possible to carry out resistivity measurements between the half-rings placed at different vertical depths; in this case resistivity will be obtained at a given depth interval in the material. If the material has the same resistivity at different depths, the horizontal and vertical measurements are equivalent; if however, the resistivity of the material varies along with varying depth (as generally happens in all porous materials when they get wet and as they dry), the horizontal measurement provides resistivity at the specific depth at which the electrodes are located, while the vertical measurement provides a value which is the combination between the different resistivities of the material that is found between the electrodes present at different depths.

As an example, in Figure 4, the results of a finite element numerical simulation wherein the penetration of water into the concrete is simulated, where the depth of the concrete is shown on the axis of abscissa and the resistivity is shown on the axis of ordinate.

The presence of two pairs of half-rings is considered, one at the depth of 5 mm and another pair at the depth of 10 mm.

When concrete is very dry, the electrical resistivity (ρ) is very high (over 100000 Ω•m), whereas, when it is wet with water, the electrical resistivity decreases significantly (up to about 100 Ω•m). The waterfront (Sw) was fed starting from the outer surface (0 mm) up to the depth of 25 mm. In the case where the measurement is carried out horizontally between the half-rings placed at 5 mm, it is observed that the electrical resistivity decreases sharply exactly when the waterfront reaches the depth of 5 mm. The same result is also obtained with the next pair, placed at 10 mm, when the waterfront continues to advance. If the measurement is carried out vertically (+ symbol), between the electrodes placed at 5 mm and 10 mm, the sharp decrease in the electrical resistivity is obtained only when the waterfront reaches the same depth as the electrode placed at the greater depth i.e. 10 mm. The measurement obtained before the water reaches the deepest electrode is the combined resistivity between 5 and 10 mm.

In the case of application in existing structures, to measure the resistance of concrete (or any other porous material, such as those of the walls) it is necessary to use two probes 100 and 101 arranged side-by-side at the same depth (Figure 3); in this case it is necessary to use a mortar/grout 21 for the fixing thereof in the holes 22 made in the structure.

The first probe 100 has a pair of half-rings denoted with numerical references 25 and 26. The second probe 101 has a pair of half-rings denoted with numerical references 27 and 28.

The measurement is carried out by short-circuiting the electrodes of each probe placed at the same depth, i.e. the half-rings 25 and 26 and the half-rings 27 and 28, and by making the measurement between the electrodes formed by the pairs of short-circuited half-rings, i.e. 25-26 and 27-28, of the two probes which are at the same depth (measured horizontally). In this way the resistivity ρ_{tot} is obtained.

The distance between the probes must be established on the basis of the maximum diameter of the aggregate used to produce the concrete of the structure. If the distance is less than the maximum diameter of the aggregate, the risk is that of having only the aggregate between some of the electrodes and therefore not obtaining the resistivity of the concrete; in the simulations and experimental tests carried out a distance of 50 mm between the probes was considered, which can be suitable in most cases.

The presence of electrodes having half-ring geometry allows high flexibility in the case of application of the probes in existing structures. In particular, it allows to obtain more precise measurements of the penetration of the wet front (by measuring the variations in the mortar/grout). To increase the robustness of the probe (in the event that a reading problem with a half-ring occurs, for example due to the presence of a filling defect, it is possible to exclude it and keep the other half-ring, which is arranged at the same depth, in order to carry out the measurements). To consider, and eliminate if necessary, the contribution in the measurement of the resistivity of the mortar/grout, used for fixing the probes, in the measurement of the resistivity of the concrete.

In this regard, the experimental results and the numerical simulations have shown that the effects of the cement grout on the measurement of the electrical resistivity of concrete depend on the thickness of the cement grout (and consequently on the diameter of the holes made for fixing) and on the possible difference between the electrical resistivity of the cement grout and that of concrete. When the resistivities of the two materials differ substantially, in order to obtain the measurement of the resistivity of the concrete (which is the necessary measurement to obtain for example an estimate of the corrosion rate of the reinforcements) it is necessary to eliminate the contribution provided by the electrical resistivity of the contact material of the cement grout.

In order to eliminate the contribution of the grout from the value of the concrete, the process is as follows.

The electrical resistivity of the used cement grout can be obtained by carrying out the measurement between the pairs of half-rings 25 and 26 and/or 27 and 28, of each probe placed at the same depth (the results of the numerical simulations have shown that the distribution of current between the two half-rings remains confined within the cement grout). The resistivity ρ_{bo} is therefore obtained (in this case it is assumed that the measure of the resistivity of the grout is identical for the two probes 100 and 101 and it is sufficient to carry out the measurement in one of the two probes).

Once this value is known and the resistivity ρ_{tot} between the electrodes 25-26 and 27-28 of the two probes that are at the same depth (horizontally) is measured, which is the weighted sum of the electrical resistivity of the concrete 20 present between the probes and the resistivity of the grouts 21 in contact with the two probes, it is possible (by knowing the geometric parameters of the system, i.e. geometry of the probe and distance between the probes, which can be determined by way of numerical simulation) to obtain the resistivity of only the concrete.

$$\rho_{cls} = (\rho_{tot} * k_{tot} - 2 * \rho_{bo} k_{bo}) / k_{cls}$$

Wherein

ρ_{tot} is the total resistivity,

ρ_{bo} is the resistivity of the grout,

ρ_{cls} is the resistivity of the concrete,

k_{tot}, k_{bo}, k_{cls} are the respective geometric parameters of the system.

As an example (Figure 5) the trend of the electrical resistivity ρ (Ω•m) is reported both in the case of probes installed in new structures (curve b) and in the case of probes installed in existing structures (curve a) and placed at the depth of the reinforcement and the corrosion rate of the reinforcement Vcorr (µm/year) (curve c) during the advancement of the waterfront in time T(h) from the concrete surface towards the reinforcement.

When the resistivity decreases the corrosion-rate shows a sudden increase. It is observed that the electrical resistivity of the concrete and the corrosion rate are inversely correlated with one another and that when one quantity varies, the other also varies proportionally. Therefore, given the correlation between the corrosion rate of the reinforcements and the electrical resistivity of the concrete, it is possible, through resistivity measurements, to obtain an estimate of the corrosion rate of the reinforcements.

Therefore, this probe can allow, in new or existing structures, to monitor:

- the corrosion conditions of the reinforcements in carbonated concrete which have different concrete covers,

- the correct filling of the sheaths in the post-tensioned prestressed concrete structures,

- the humidity conditions in the concrete (or in any porous material) at different depths,

- the stages of setting and developing the mechanical strength of the concrete, so as to also check that the prescribed seasoning has been carried out,

- the internal temperature of the material.

In particular, regarding the corrosion of the reinforcements, the probe can provide an estimate of the propagation of the corrosion of reinforcements that have different concrete covers in reinforced concrete structures affected by carbonation, thus allowing to determine the residual life of the structure and to plan the maintenance/restoration.

It allows, furthermore, to check the effectiveness of any maintenance carried out (such as the use of coatings used to keep the concrete dry).

This probe can also be used to evaluate the penetration of aggressive agents into the concrete cover (in particular carbonation).

It can also be used in walls, to evaluate internal humidity conditions at different depths.

It can be used in any type of structure (e.g. civil buildings, infrastructures, industrial tanks, etc.) made of concrete, reinforced concrete, prestressed concrete and, in general, of porous materials (such as those forming the walls).

CLAIMS

1. A system for measuring the electrical resistivity of concrete in already existing structures comprising a first probe and a second probe placed in two separate holes of a construction; said first and second probes comprise: a tubular element (10); a first electrode (11) and a second electrode (12), placed at the same height to form a pair of electrodes (11, 12) electrically isolated from one another by interposing an insulating material (14); a plurality of said pair of electrodes (11, 12) are placed on said tubular element (10) at different heights.

2. The probe according to claim 1, characterized in that said first electrode (11) and said second electrode (12) are made in the shape of a half-ring and are placed opposite one another.

3. The system according to claim 1, characterized in that the half-ring electrodes placed at the same height are separated by an electrical insulating material.

4. The system according to claim 1, characterized in that the distance between the half-rings at the same height (14) is less than 5 mm.

5. The system according to claim 1, characterized in that said tubular element (10) is embedded in concrete.

6. The system according to claim 1, characterized in that it comprises a temperature sensor.

7. The system according to claim 1, characterized in that said tubular element (10) is made of an electrical insulating material and is filled with a resin.

8. A method for measuring the electrical resistivity of concrete in already existing constructions characterized by using a first probe and a second probe, according to claim 1, placed side-by-side and each surrounded by grout, characterized in that it comprises steps: measuring the resistivity between two electrodes placed at the same height as said first probe and providing a first resistivity value; measuring the resistivity between an electrode of said first probe and an electrode of said second probe placed at the same height and providing a second resistivity value; calculating said electrical resistivity in concrete by eliminating the resistivity of said grout.

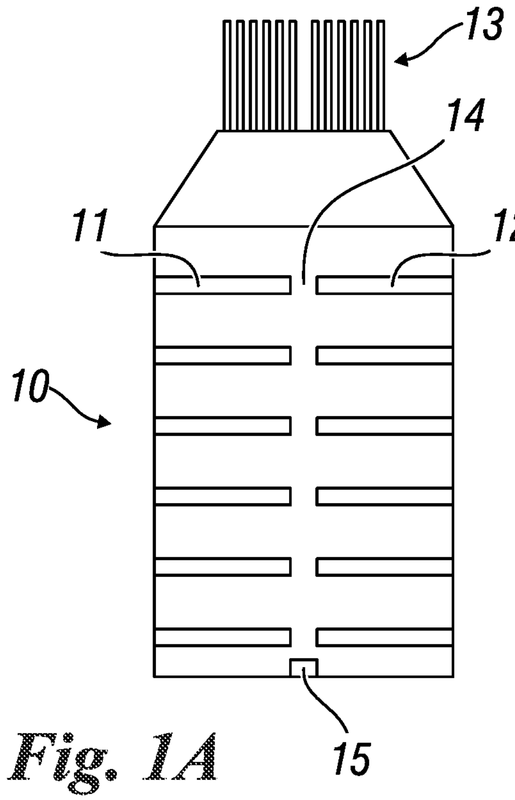


Fig. 1A

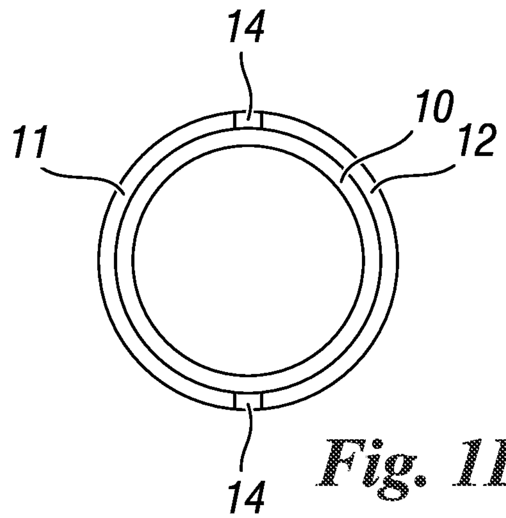


Fig. 1B

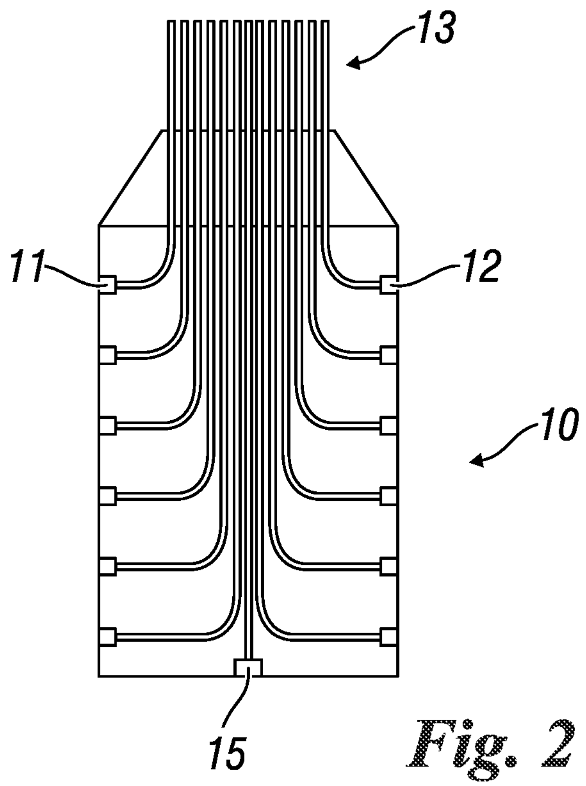
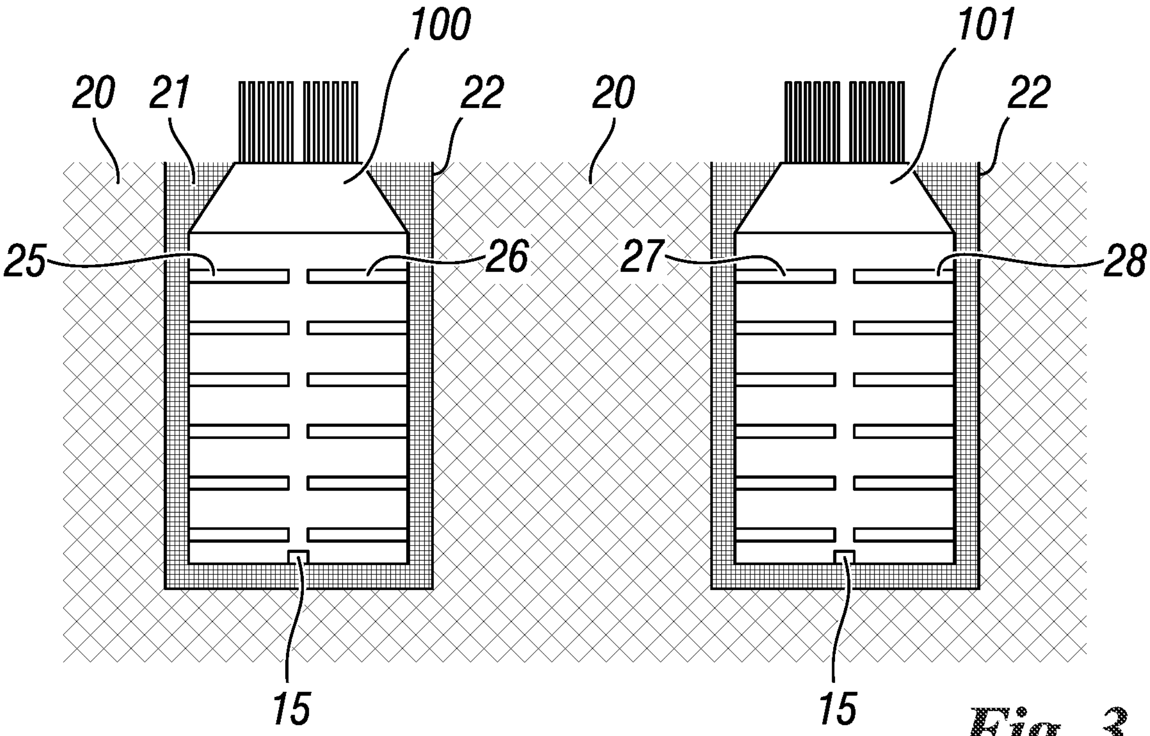


Fig. 2


100
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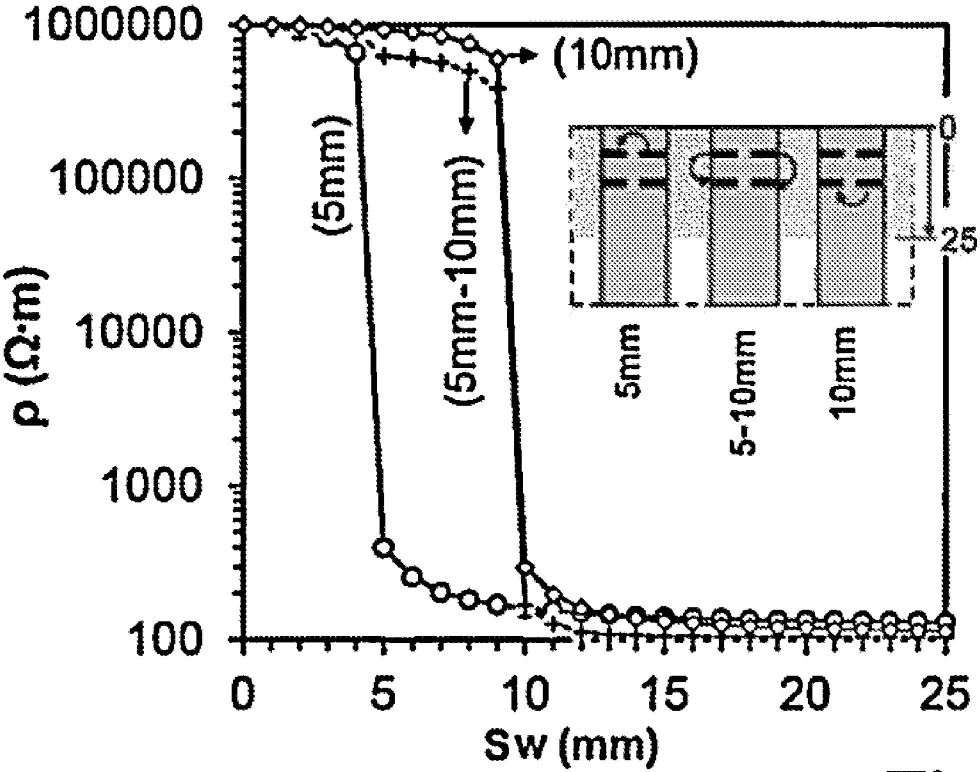
15

Fig. 3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10000
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5
10
15
20
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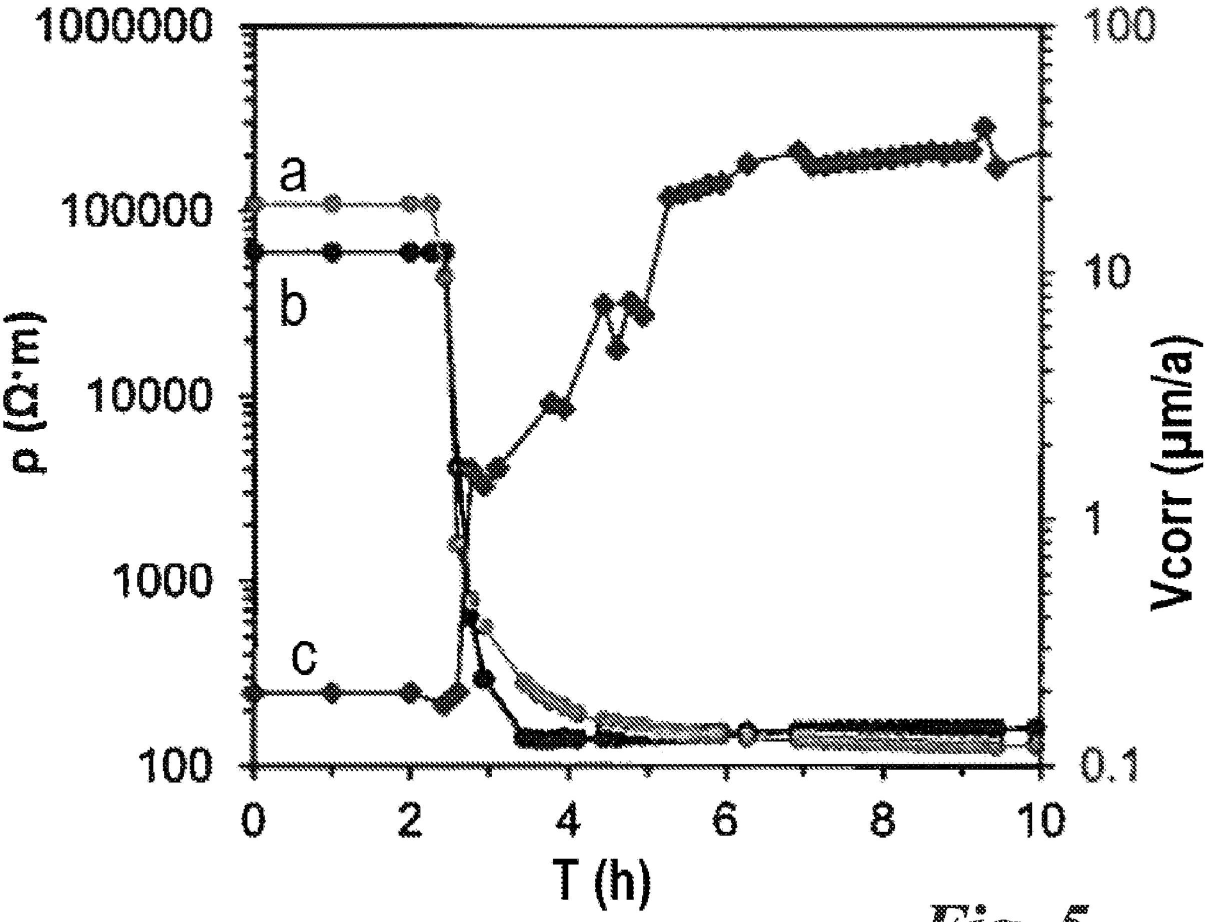
(10mm)
(5mm)
(5mm-10mm)
0
25
5mm
5-10mm
10mm

Fig. 4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ρ (Ω·m)
a
b
c
0
2
4
6
8
10
T (h)
100
10
1
0.1
Vcorr (µm/a)

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2020/053056

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01N33/38 G01N27/04
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)
G01N

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	EP 3 236 258 A2 (GHODS POURIA [CA]; ALIZADEH ROUHOLLAH [CA] ET AL.) 25 October 2017 (2017-10-25)	1-7
A	paragraphs [0018] - [0020]; figure 1 paragraph [0028] paragraph [0043]; figures 7, 8 paragraph [0052] paragraphs [0076], [0077] -----	8
X	CN 107 860 977 A (HARBIN INST TECHNOLOGY) 30 March 2018 (2018-03-30)	1-7
A	paragraphs [0019] - [0022]; figures 1, 2 -----	8
A	WO 2015/150463 A1 (DUBLIN INST OF TECHNOLOGY [IE]) 8 October 2015 (2015-10-08) page 9, line 10 - page 10, line 16 -----	8
	-/--	

[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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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 June 2020	26/06/2020

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Marzocchi, Olaf

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	CN 207 557 160 U (LIN LIWEN) 29 June 2018 (2018-06-29) paragraphs [0018] - [0021] -----	8
A	ES 2 593 960 A1 (INST TECNÓLOGICO DE MAT DE CONSTRUCCIÓN Y ROCAS ORNAMENTALES [ES]) 14 December 2016 (2016-12-14) page 5, lines 16-27 page 6, lines 6-26 page 7, lines 5-32 page 9, lines 11-29 -----	8
A	CN 108 956 684 A (HARBIN INST TECHNOLOGY) 7 December 2018 (2018-12-07) paragraph [0019]; figures 1-3 -----	1-8

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2020/053056

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
EP 3236258	A2	25-10-2017	CA 2962684	A1	30-09-2017
			EP 3236258	A2	25-10-2017
			US 2017284996	A1	05-10-2017
			US 2019242868	A1	08-08-2019
CN 107860977	A	30-03-2018	NONE		
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CN 207557160	U	29-06-2018	NONE		
ES 2593960	A1	14-12-2016	NONE		
CN 108956684	A	07-12-2018	NONE		