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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
17 September 2015 (17.09.2015)

WIPO | PCT

(10) International Publication Number
WO 2015/136494 A1

(51) **International Patent Classification**:
G02B 6/44 (2006.01) *G02B 6/46* (2006.01)

(21) **International Application Number**:
PCT/IB2015/051852

(22) **International Filing Date**:
13 March 2015 (13.03.2015)

(25) **Filing Language**: Italian

(26) **Publication Language**: English

(30) **Priority Data**:
RM2014A000128 13 March 2014 (13.03.2014) 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, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, 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, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, 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).

Published:

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

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

WO 2015/136494 A1

(54) **Title**: PROCESS AND APPARATUS FOR THE INSTALLATION OF OPTICAL FIBER SENSORS ONTO PIPES

(57) **Abstract**: There is provided a process for the installation of optical fiber sensors onto pipelines, the process is characterized in that it comprises the following steps: Cleaning of a surface portion of the pipeline at a surface portion where said optical fiber sensors have to be applied; Spreading on to said surface portion of said pipeline of a layer of adhesive; Positioning with controlled tension of one or more optical fibers onto said layer of adhesive and along the entire length of said pipeline; and controlling the positioning of said one or more optical fibers along said pipeline, by positioning said one or more optical fibers onto the entire predetermined length of said pipeline. It also provided an apparatus for carrying out the present process.

"PROCESS AND APPARATUS FOR THE INSTALLATION OF OPTICAL FIBER SENSORS ONTO PIPES"

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DESCRIPTION

The present invention relates to a process for the installation of optical fiber sensors onto pipes and, more specifically, to a process for the installation of optical fiber sensors along a pipe.

The object of the present invention it is also an apparatus to perform the above process.

Prior art

In recent years, optical fiber sensors have gained an important role in different fields of application, such as in the field of structural monitoring or in the field of environmental monitoring. This success is due to the large possibility that these sensors offer to sense/detect the physical quantity of interest (i.e., such as temperature and/or strain), with continuity and over long distances.

Further advantages upon using the optical fiber reside in the low cost, and immunity to electromagnetic interference of the optical fiber when used as the sensitive element to sense the physical quantity of interest (for example, as described by J. Dakin and B. Culshaw in "Optical fiber sensors", Artech House, Boston, 1997).

As it is known, the deformation systems based on deploying an optical fiber require that the fiber itself be mechanically constrained to the structure to be monitored, by attaching the former to the latter by means of adhesive or otherwise.

Furthermore, in the case of measurements on pipes having typically circular section, the use of three fibers parallel arranged along the pipe allows to obtain the value of the displacement in the two directions which are orthogonal to the axis of the pipe, and for each section of the pipe (i.e., see "Vectorial dislocation monitoring of pipes by use of Brillouin-based optical fiber sensors", R.

Bernini, A. Minardo and L. Zeni, Smart Mater. Struct., vol. 17, pp. 015 006, 2008).

Traditionally, the installation of optical fibers along the pipes it is done manually (i.e., Carlos Borda, Marc Nikles, Etienne Rochat, Grechanov Alexander, Alexander Naumov, Valeriy Velikodnev "Continuous Real-Time Pipes Deformation, 3D Positioning and Ground Movement Monitoring Along The Pipe", Sakhalin-Khabarovsk-Vladivos 8th Technology Conference 2013).

An example of this methodology for the applying of optical fibers sensors onto pipes it is described in WO2011039592A1, where it is provided the applying of three sensors arranged parallel one to each other and with respect to the longitudinal axis of a pipe having circular cross section, each sensor comprising one or more optical fibers.

Nevertheless, this methodology has a drawback due to the fact that for the installation of the sensors it is required considerable effort in terms of the man power, especially when the length of the route along which the fiber must be applied consists of several kilometres, making the use of this installing methodology addressed to only "non-systematic" applications, therefore not being suitable for long pipelines such as, for example, gas pipelines, oil pipelines, and aqueducts.

Further, the manual installation of the fibers also presents the drawback of being subject to errors in the angular positioning of the fiber onto the pipe, which affect the quality of the data obtained from the readings of deformation.

Therefore, there is a real need in this field to provide an automatic system for implementation of the optical fiber sensors, which allows on one hand to reduce the installation costs, and on the other hand to minimize the positioning errors of the fiber along the pipes. Further, the need is due in view of providing an industrial product or system that is capable of detecting deformation,

displacement, temperature, and finally leaks (leak detection) along the entire length of the piping.

Therefore, the aim of the present invention is to solve the aforesaid drawbacks by providing a systematic process for the automatic positioning of optical fiber sensors along pipes, and which process ensures reliability and repeatability.

Another object of the present invention is to provide an apparatus which automatically realize the above process.

Brief description of the invention

The present invention provides a process and an apparatus which allow:

- Automatically installing on a pipeline more than one optical fiber, and preferably three optical fibers, arranged 90° or 120° one with respect to the other, and in a parallel arrangement with respect to the longitudinal axis of the pipeline;
- Cleaning the surface pipe section onto which the fiber has to be positioned;
- Gluing each fiber onto the pipe surface; and
- Placing a sheath onto the glued fibers for the mechanical protection thereof.

Thus, the present invention provides a process and an apparatus substantially according to the appended claims.

Detailed description of the invention

A detailed description of a preferred embodiment of the method and the apparatus of the present invention will now be given, by way of non limiting example and with reference to the appended drawings, wherein:

Figure 1 is a perspective schematic view of a pipe onto which optical fibers have been applied according to the process of the present invention;

Figure 2 is a front schematic view of the apparatus for the positioning of optical fibers onto a pipeline and according to the present invention;

Figure 3 is a perspective schematic view from above and showing a part of the apparatus of the present

invention in detail;

Figure 4 is a generic perspective view from one side of a part of the apparatus of the present invention;

Figure 5 is a perspective view showing in detail a part of the apparatus of the present invention;

Figure 6 is perspective partial view showing in detail a part of the apparatus of the present invention when positioned onto a pipe;

Figure 7 is a schematic view showing logic control of the apparatus of the present invention; and

Figure 8 is a schematic view showing a function of the apparatus of the present invention.

Will be now described the process of the present invention with reference now to the drawings.

According to the present invention, the process comprises the following main steps:

a) Cleaning of the surface of the pipe at the surface part onto which the optical fibers will be positioned and subsequently glued. The purpose of cleansing the surface it is to remove grease or other substances which may affect the quality of the bonding;

b) Laying on the cleaned surface of the pipe a layer of adhesive;

c) Positioning by a controlled tension of one or more optical fibers onto said layer of adhesive and along the entire length of the pipe; and

d) Displacing while advancing in a controlled manner along the pipe, so as to have the one or more optical fibers in an longitudinal arrangement parallel to the pipe and throughout the desired length.

In order to achieve each step of the above illustrated process, the invention provides an automated apparatus which is fitted both to perform the cleansing of the surface pipe, and to perform the positioning of the optical fiber onto the pipe, and the bonding thereof to the surface of the pipe, as well as the positioning of an eventual protective sheath (coating) of the fibers.

According to one aspect of the apparatus of the present invention and with particular reference to Figures 4 and 5, it is provided that the apparatus be able to place more than one fiber along the longitudinal axis of the pipe and in an arrangement of 90° or 120° spaced one relative to another.

According to another aspect of the apparatus of the present invention and with reference now to Figure 8, the same it is equipped with a verifying system for checking the continuity of the optical fibers during the installing steps thereof onto the pipe, so as to be able to perform any "splicing" operations of the fiber to be needed and well before that the adhesive has set. More precisely, in case of a part of the fiber results damaged (interrupted) during the positioning step onto the pipe, an alarm system immediately notify an operator, and allowing the latter for promptly intervene.

GLUE SUPPLYING AND POSITIONING SYSTEM ONTO THE PIPE

The bonding system of the fibers onto the pipeline is dimensioned as per the pumping area of the glue, according to the type of pipe onto which the fibers must be positioned. In fact, for example, if the fibers are to be positioned onto a steel pipe having no lining thereon, it will be required a mono or bi-component polyurethane or epoxy adhesive.

Therefore, the adhesive pumping section (i.e., area) will be chosen according to the choice of adhesive.

The present applicants have performed a test (Figure 2) on a specific section of pipe, wherein the fibers have been applied onto a steel pipe having diameter 6", and coated with polyethylene.

Therefore, it was identified a low viscosity mono component glue, and it was pumped with two peristaltic pumps (Figure 2), the first of which performing the pumping of the glue onto the pipe surface before the implementation of the fibers along the longitudinal axis and for each single fiber, while the second pump performing the pumping

of the glue onto the fiber surface and after the latter has been positioned onto the tube.

As it is illustrated in detail in Figure 3, both in the first glue pumping step (i.e., the glue is positioned onto the pipe surface and before the installation of the fiber), and in the second glue pumping step (i.e., the glue is positioned onto the fiber and after the installation of the latter onto the pipe), an aluminium terminal member having a Teflon terminal spreader it is provided, the terminal member causing in the first step the spreading of the glue onto the pipe surface, whilst in the second step to adhere perfectly the fiber onto the pipe by biasing the former onto the latter and suitably spreading the adhesive onto the fiber.

FIBERS SUPPLYING AND POSITIONING SYSTEM ONTO THE PIPE

The supplying of the fiber onto the pipe represents the most delicate step of the whole process of implementation.

In fact, excessive tension applied to the fiber may exert to the same an excessive stress (strain), and limit the sensing field (range) due to excessive pre-tension and, in the worst case, determining the break.

As it is illustrated in Figure 4, according to the invention the apparatus comprises a system that is composed of three aluminum coils rotatable mounted onto a shaft, through polymeric sliding bearings. The choice of this type of bearing it is determined by the need of allowing the quick removal of a coil for the replacement thereof upon ending of the fiber to be installed.

Each fiber coming from the respective coil it is guided via a copper or steel tube, inside of which a Teflon tube it is inserted for the easing sliding of the optical fiber therein. As it is illustrated in detail in Figure 5, the insertion of the fibers in their respective metallic tubes, is achieved through a conical inserting section capable of avoiding abnormal friction associated with the horizontal displacement of the fiber onto the spool during

its deployment.

According to this arrangement, the following objectives are achieved:

1) The optical fiber it is not subject in any deployment condition to too small "radii of curvature" (bending) which may damage the same;
2) The optical fiber it is mechanically protected by the copper or steel tube;
3) Through the Teflon tube, the fiber it is not subjected to excessive friction that could damage the same.

As it is illustrated in Figure 6, the optical fiber is then guided through the terminal Teflon member up to the exact point where the fiber has to be positioned onto the pipe, and without exposing the same to any kind of interference that may cause breakage thereof.

PROTECTIVE SHEATH (OR COATING) POSITIONING SYSTEM

Once the fiber has been positioned and fixed onto the pipe, the apparatus provides the positioning of a protective sheath (or coating) onto the fiber, and in order to protect it from subsequent stresses that could damage the same.

The "coating" will be positioned according to the type of pipe onto which the fiber is positioned, by covering the latter with a polyurethane structural sheath or with a polyurethane adhesive tape. In the first case, the polyurethane sheath can be positioned via a nozzle system which provides for its positioning downstream of the bonding of the fiber onto the pipe.

Further, the pumping unit features will vary according to the type of material (glue) to be deposited.

AUTOMATIC DISPLACING UNIT

The apparatus also comprises an automatic displacing unit, which provides for the following functions:

1) Displacing the apparatus onto and along the pipeline at a controlled speed;
2) Ensure the horizontal positioning of the apparatus during the displacing thereof; and

3) Correlate the pumping rate of the glue dispensing pump and of the protective coating dispensing pump to the displacing speed of the apparatus onto the pipeline.

Schematically, the management of the control unit (PLC) and its interfacing with all the devices of the apparatus according to the present invention it is schematically shown in Figure 7.

More specifically, the control unit (PLC) acquires the values relating to the inclination of the apparatus with respect to the transversal axis through a tilt sensor, and maintains the apparatus positioned in an exact horizontal position by controlling the rotating speed of a couple of displacing motors in a differential manner, and then correlates the pumping rate for dispensing glue with the moving speed of the apparatus.

OPTICAL FIBER INTERRUPTION DETECTING UNIT

The continuity of an installed optical fiber is a key element in the whole process of quality control during the installation steps. As a matter of facts, the breakage of a fiber would compromise the whole sensing operation of the measuring system.

With particular reference now to Figure 8, within each coil there is provided a sensing circuit capable of detecting the continuity of the installed fiber, and to transmit the relevant alarm signal to the control unit (PLC) in the event that an interruption is detected.

The continuity monitoring unit operates according to the following scheme:

a) A laser emitter it is connected at the free end of the fiber to be installed;

b) The detecting circuits provided within each coil are connected to the respective ends of the fibers, and detect the laser beam transmitted by the emitter connected to the free ends of the fibers (starting point of installation);

c) In the event that a fiber is interrupted, the circuit detects the absence of the signal coming from the

laser source and transmits an alarm (via ZigBee communication) to the PLC, the former activates an audible alarm and indicates which of the three fibers is interrupted.

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CLAIMS

1. A process for the installation of optical fiber sensors onto pipelines,
characterized in that it comprises the following steps:
- Cleaning of a surface portion of the pipeline at a surface portion where said optical fiber sensors have to be applied ;
- Spreading on to said surface portion of said pipeline of a layer of adhesive;
- Positioning with controlled tension of one or more optical fibers onto said layer of adhesive and along the entire length of said pipeline; and
- Controlling the positioning of said one or more optical fibers along said pipeline, by positioning said one or more optical fibers onto the entire predetermined length of said pipeline.

2. The process for the installation of optical fiber sensors onto pipelines according to the preceding claim, wherein said step of positioning one or more optical fibers onto said pipeline provides said fibers to be arranged in a longitudinal arrangement parallel to the pipe and for the whole predetermined length.

3. The process for the installation of optical fiber sensors onto pipelines according to claim 1 or 2, wherein said step of positioning said optical fibers onto said pipeline provide three optical fibers arranged onto said pipeline in a parallel arrangement with respect to the longitudinal axis of said pipeline and parallel one fiber with respect to the other, said optical fibers being spaced between them an angle of 90° or 120° with respect to the cross section of the pipeline.

4. The process for the installation of optical fiber sensors onto pipelines according to claim 1 or 2 or 3, wherein said step of positioning said optical

fibers onto said pipeline further comprises a step of positioning a protective sheath or coating onto said optical fibers.

5. The process for the installation of optical fiber sensors onto pipelines according to any of the preceding claims, further comprising a step of verifying of the continuity of the optical fibers during the whole process.

6. Apparatus for the installation of optical fiber sensors onto pipelines,

characterized in that it comprises:

- Means for supplying and positioning adhesive onto said pipeline;
- Means for supplying and positioning said optical fibers onto said pipeline;
- Means for positioning a protective sheath or coating onto said optical fibers;
- Moving means for moving said apparatus in a controlled and automated manner onto said pipeline; and
- Detecting means for detecting an interruption of continuity of said optical fibers.

7. The apparatus for the installation of optical fiber sensors onto pipelines according to the preceding claim, wherein said means for supplying and positioning adhesive onto said pipeline comprises an applicator for spreading adhesive onto said pipeline and to bias said optical fiber to adhere perfectly onto said pipeline and for spreading said adhesive onto said fiber.

8. The apparatus for the installation of optical fiber sensors onto pipelines according to claim 6 or 7, wherein said means for supplying and positioning said fibers onto said pipeline comprises:

- A unit that includes a coil for each fiber to be fed out onto said pipeline, the coil being rotatably mounted onto said apparatus;

- A supplying tube for each optical fiber to be supplied; and
- A guide member for each fiber to be fed out onto said pipeline, the guide member comprising a supply terminal of said fiber onto said pipeline.

9. Apparatus for the installation of optical fiber sensors onto pipelines according to claim 6 or 7 or 8, wherein said positioning means of a protective sheath or coating comprises a supply unit fitted with nozzles and which provides the positioning of said coating downstream the gluing of the fiber onto the pipe.

10. Apparatus for the installation of optical fiber sensors onto pipelines according to any of claims 6 to 9, wherein said moving means for moving said apparatus in a controlled and automated manner onto said pipeline comprises a PLC unit which controls the following functions:

- Controlling the displacement of said apparatus along said pipeline at a controlled speed;
- Controlling the positioning of said apparatus onto said pipeline;
- Correlate the adhesive dispensing rate and the protective coating dispensing rate with the moving speed of the apparatus onto said pipeline;

and wherein said detecting means for detecting an interruption of continuity of said optical fibers comprises:

- An electronic circuit inserted in a respective optical fiber coil, the circuit detecting the continuity of the installed fiber and transmitting to said control unit (PLC) an alarm when failure is detected.

FIG. 1

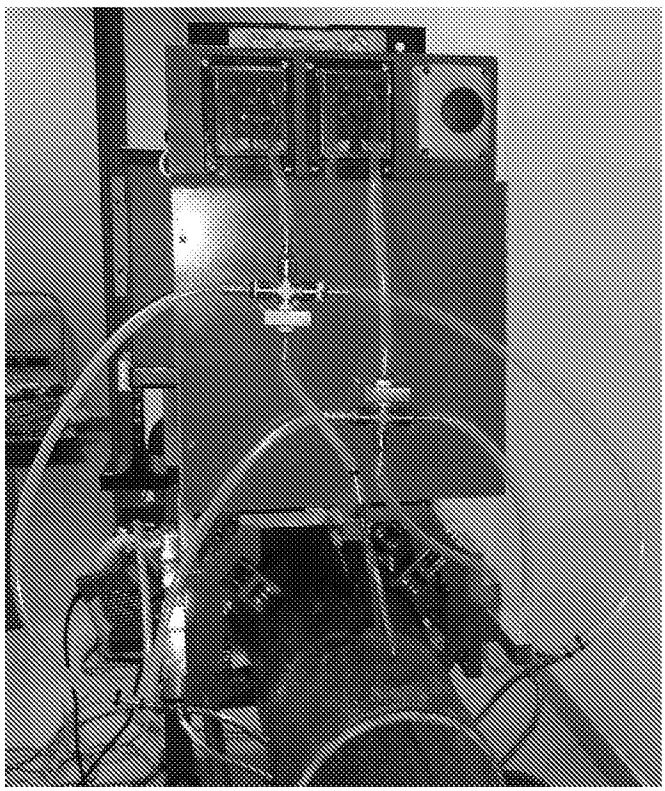

FIG. 2

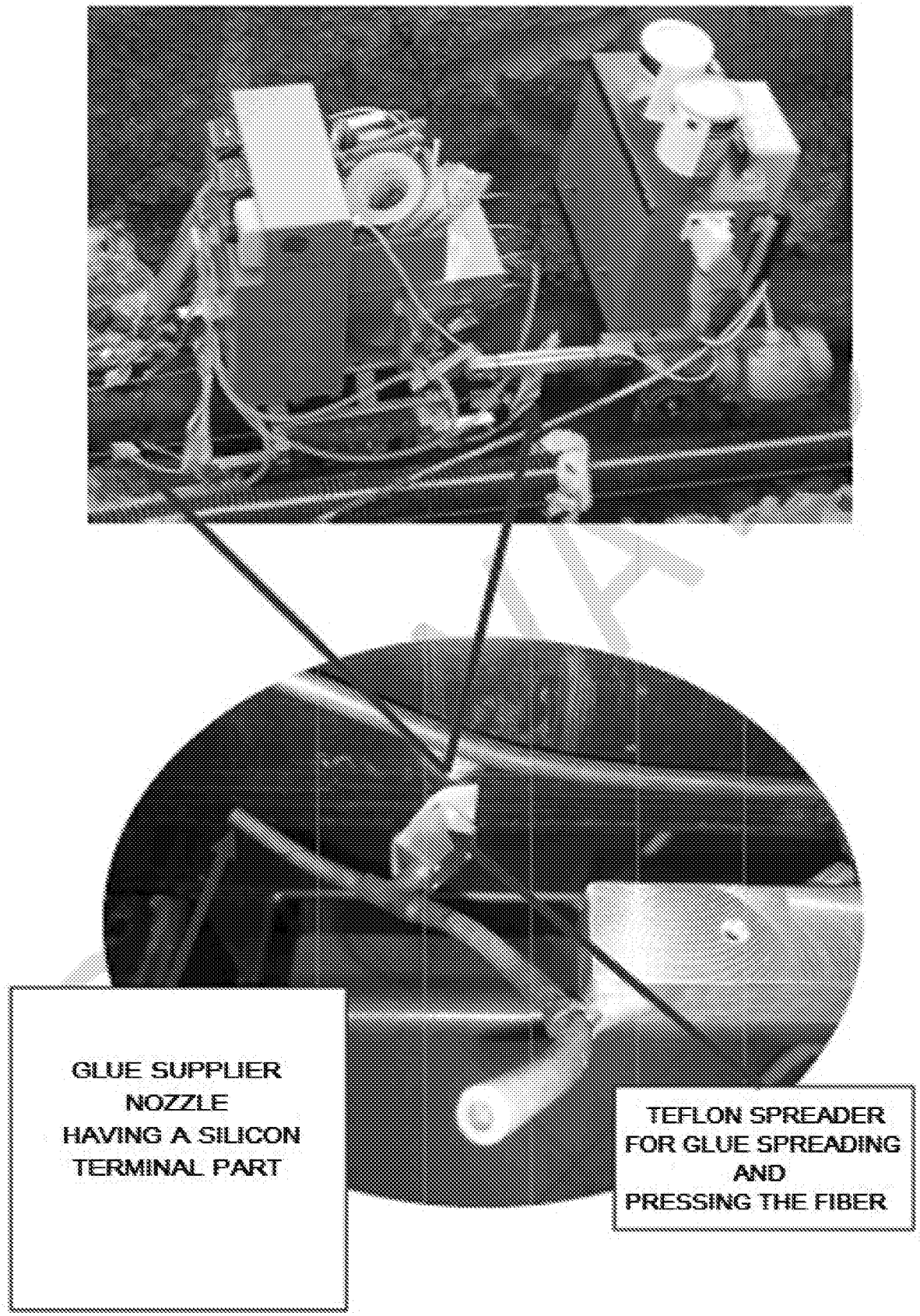
GLUE SUPPLIER NOZZLE HAVING A SILICON TERMINAL PART
TEFLON SPREADER FOR GLUE SPREADING AND PRESSING THE FIBER

FIG. 3

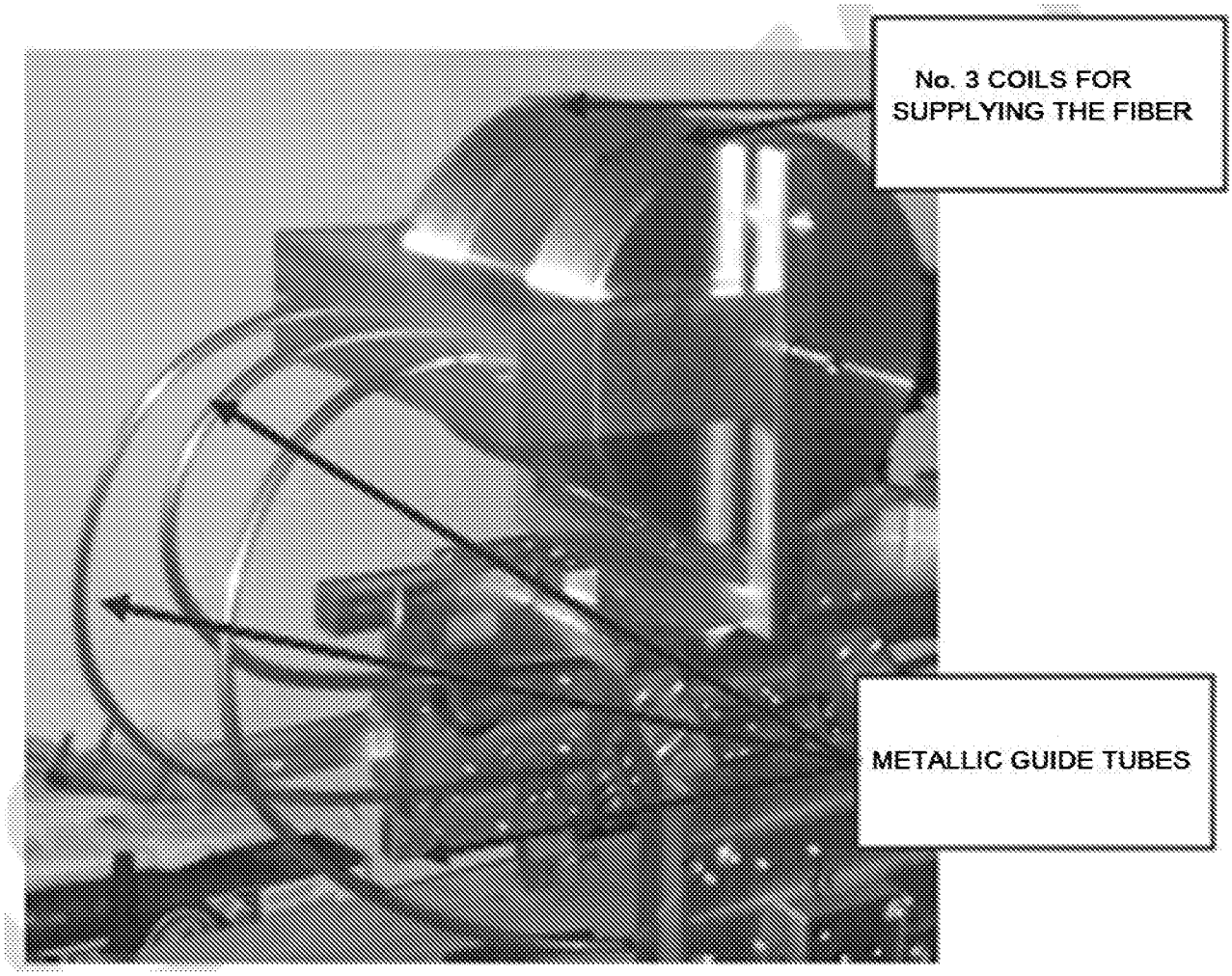

FIG. 4

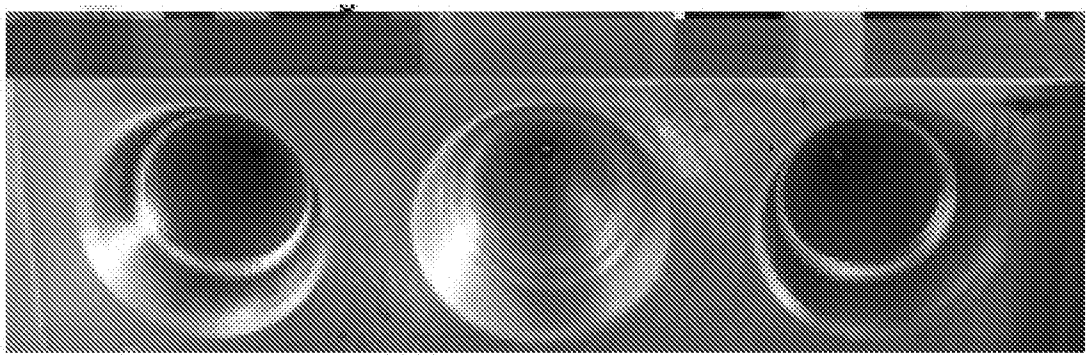

FIG. 5

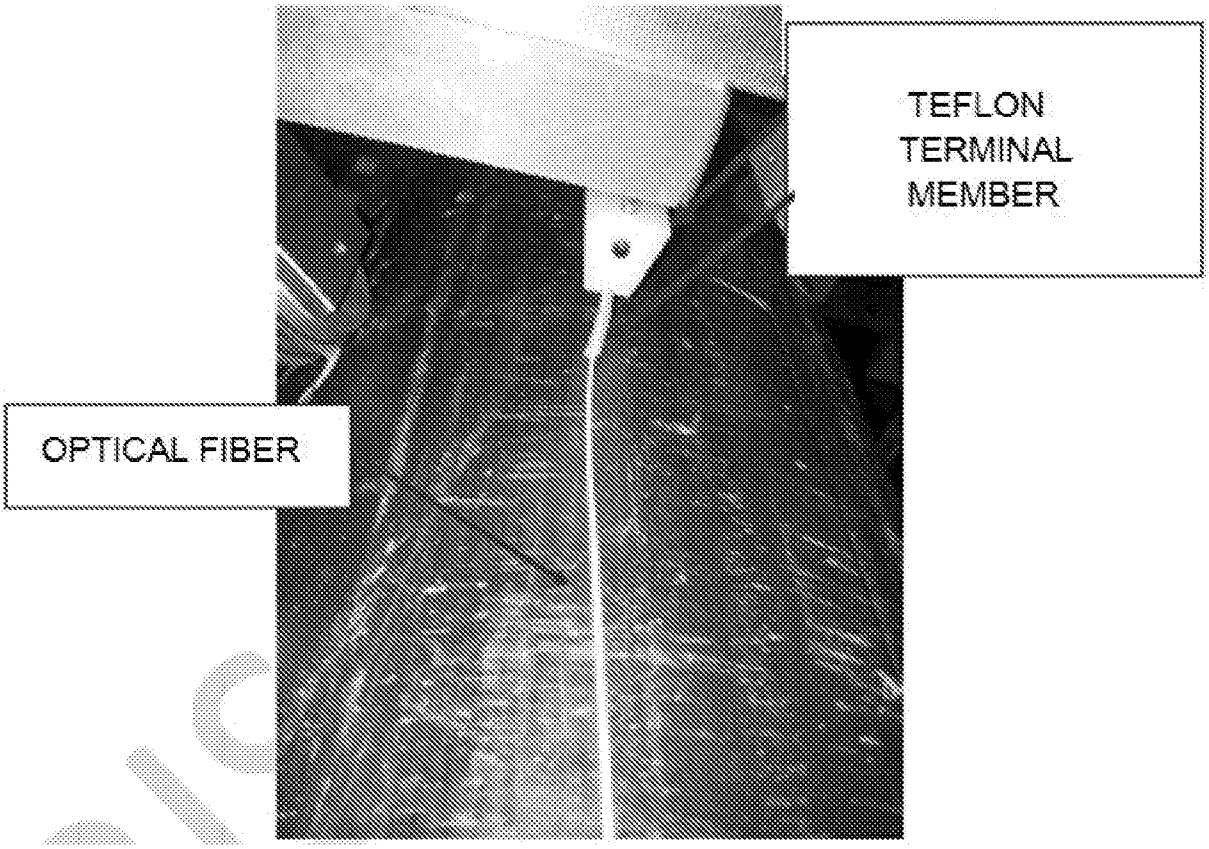
TEFLON
TERMINAL
MEMBER
OPTICAL FIBER

FIG. 6

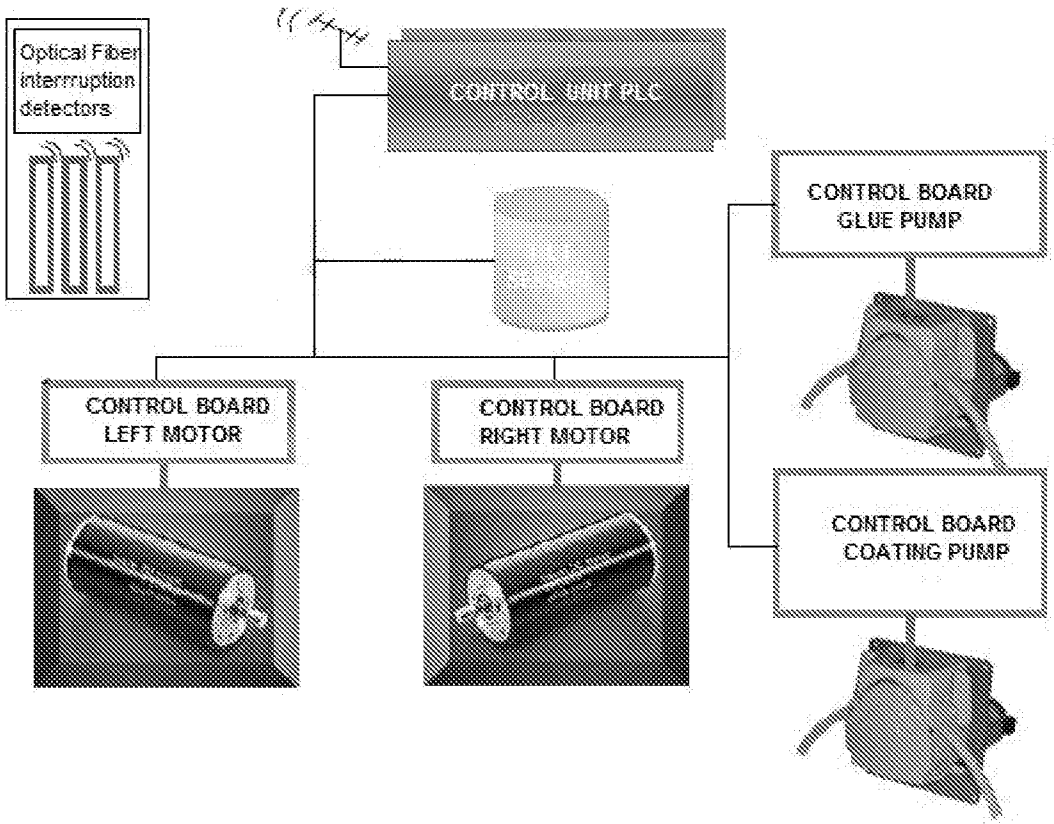
Optical Fiber interruption detectors
CONTROL UNIT PLC
CONTROL BOARD GLUE PUMP
CONTROL BOARD LEFT MOTOR
CONTROL BOARD RIGHT MOTOR
CONTROL BOARD COATING PUMP

FIG. 7

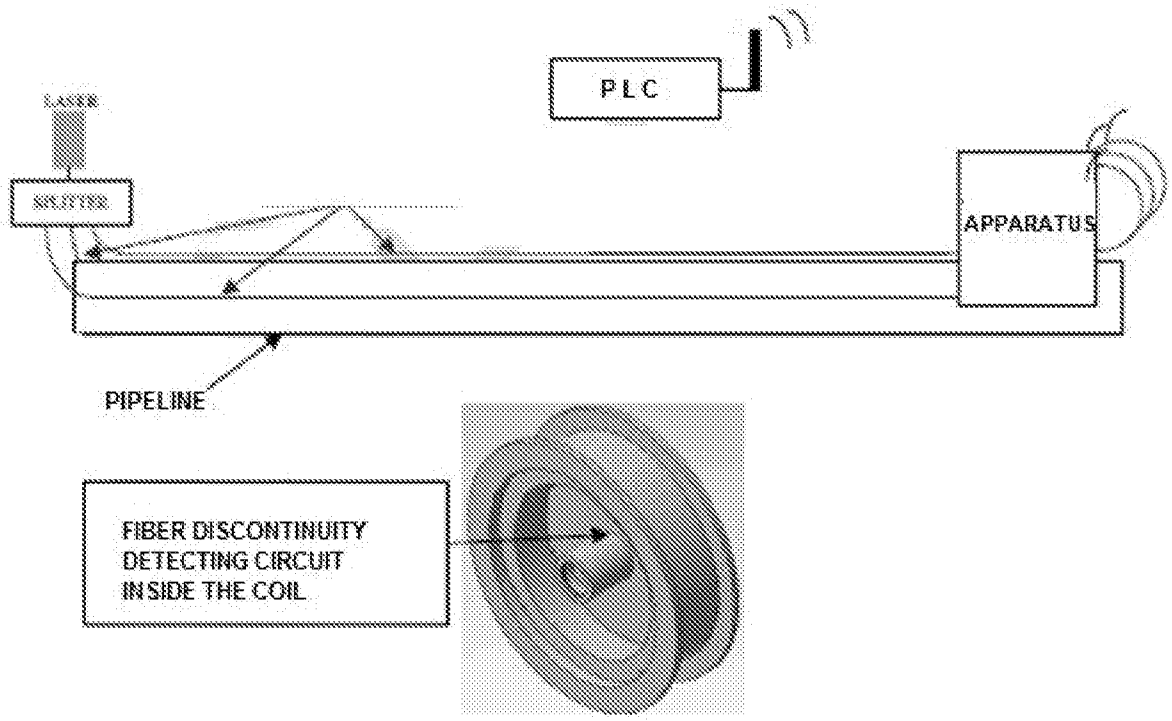
PLC
APPARATUS
PIPELINE
FIBER DISCONTINUITY
DETECTING CIRCUIT
INSIDE THE COIL

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2015/051852

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02B6/44 G02B6/46
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)
G02B F16L

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 2009/308475 A1 (STRINGFELLOW WILLIAM D [US] ET AL SRINGFELLOW WILLIAM D [US] ET AL) 17 December 2009 (2009-12-17) paragraphs [0010], [0039], [0041], [0100] figures	1-10
X	WO 2011/039592 A1 (ENI SPA [IT]; DALMAZZONE MAURO GIANNI [IT]; DE LORENZO GIANPIETRO [IT]) 7 April 2011 (2011-04-07) page 7, line 16 - page 15, line 23 figures 1/3-3/3	1-5
X	WO 2012/012362 A2 (URASEAL INC [US]; OFS FITEL LLC [US]; MALOFSKY BERNARD M [US]; MALOFSK) 26 January 2012 (2012-01-26) page 8 - page 28 figures	6-10

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

☒ 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
30 June 2015	10/07/2015

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2015/051852

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2009308475 A1	17-12-2009	US 2009308475 A1	17-12-2009
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		US 2012066987 A1	22-03-2012
		US 2014020815 A1	23-01-2014
		WO 2012012362 A2	26-01-2012