



(22) Date de dépôt/Filing Date: 2013/01/25

(41) Mise à la disp. pub./Open to Public Insp.: 2014/07/25

(45) Date de délivrance/Issue Date: 2019/06/04

(51) Cl.Int./Int.Cl. *G01V 1/18* (2006.01)

(72) Inventeurs/Inventors:

BARANOV, ALEX, CA;  
COULTER, WADE, CA;  
GRAHAM, KEITH, CA;  
HAWRYLUCK, CHRIS, CA;  
TRIFU, TIBERIUS, CA

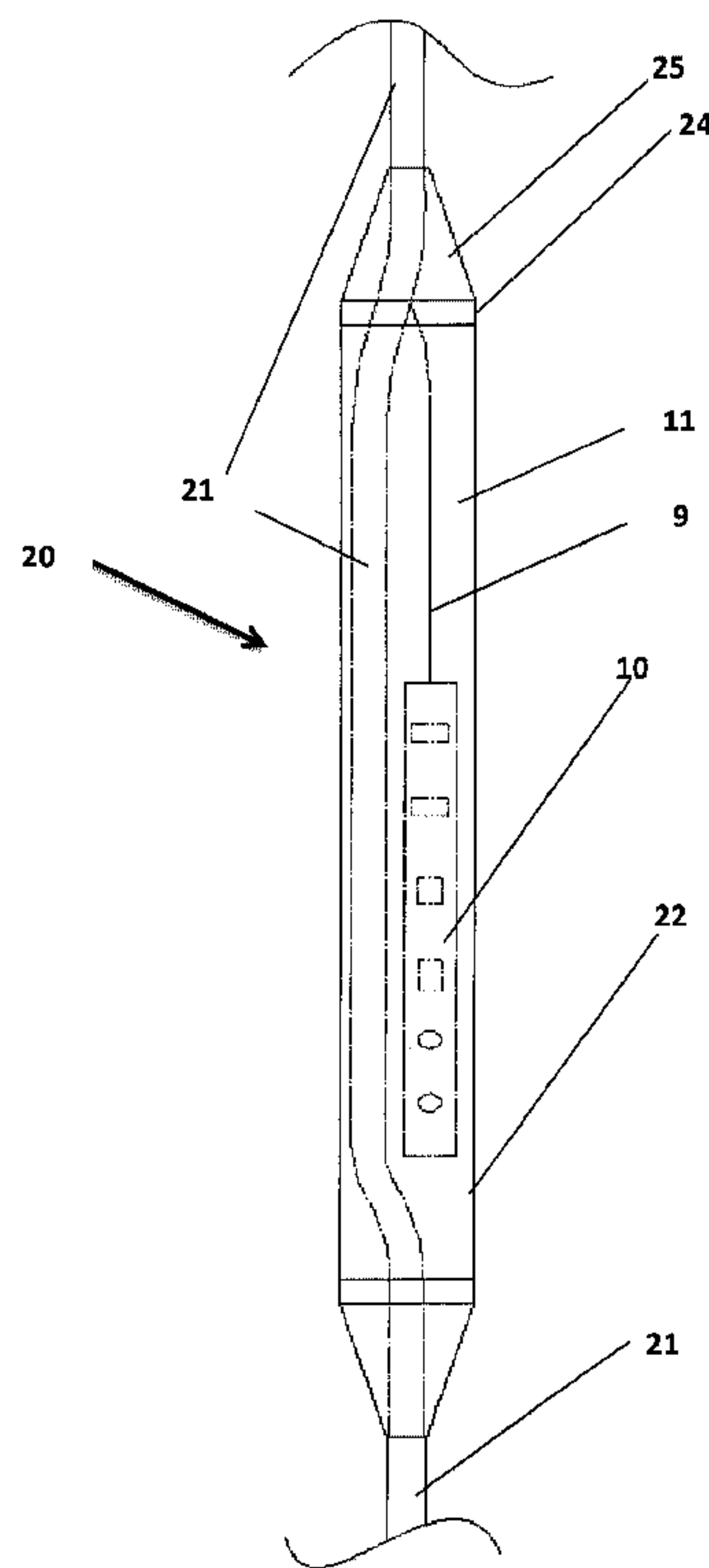
(73) Propriétaire/Owner:

ENGINEERING SEISMOLOGY GROUP CANADA INC.,  
CA

(74) Agent: RIDOUT & MAYBEE LLP

(54) Titre : OUTIL SISMIQUE DE RESEAU A PLUSIEURS CAPTEURS

(54) Title: MULTIPLE SENSOR ARRAY SEISMIC TOOL



(57) Abrégé/Abstract:

A cartridge sub-assembly which acts as a primary seal for sensor elements with an external pod housing performing the function of a secondary seal.

**ABSTRACT**

**A cartridge sub-assembly which acts as a primary seal for sensor elements with an external pod housing performing the function of a secondary seal.**

## Multiple Sensor Array Seismic Tool

### Field

The present disclosure relates to sensor tools used for micro-seismic monitoring.

5

### Background:

Micro-seismic monitoring is increasingly used to understand the geophysics which occur in the mineral extraction industries when producing petroleum and when mining ores. By generating a seismic event through production activities, or through other sources, the monitoring of the propagation of micro-displacements through the earth, i.e. monitoring the source and direction of P-waves and S-waves, will provide the mineral producers with insight into the geological formation, into its porosity, and into the structure of the earth surrounding the deposit. With this knowledge, petroleum producers can determine where to apply pressure in order to extract oil from a petroleum reservoir while minimizing the loss of reservoir pressure, while minimizing the leakage of oil product, and while minimizing the waste of extraction fluids. When mining an ore deposit, the seismic analysis of the earth surrounding the ore deposit will enable producers to decide where to drill as well as provide warning of structural instability.

20

Because S- and P-wave displacements provide the highest signal fidelity and the highest signal reliability when they are detected below the earth's surface, prior art has devised methods for deploying a string of geophones down a borehole. Witness US patent (No. 5,860,483) "Method for Installing Electronic Equipment Below Soft Earth Surface", (Author Sven O. Havig). Other Inventors have used similar deployment methods to deploy multiple sensor types in pursuit of seismic data. Witness US Patent (No. 6,888,972 B2), "Multiple Component Sensor Array Mechanism" (Author Berg et al.); and witness US Patent (No. 6,724, 319) "Acoustic Sensing System for Downhole Seismic Application Utilizing an Array of Fiber Optic Sensors". Variations on these methods have been in use since the 1950s. All of these multiple sensor arrays have in common a length of cable used for transmitting signals interspersed with sensor pods which feature an impermeable pressure and temperature resistant housing. Differences, occur as to the type of sensor used to monitor seismic events, the format as to how the signal

25

30

is transmitted to the surface (analog or digital), and the design of the seismic cable and sensor pods.

## **SUMMARY**

5 According to a first example aspect, the present disclosure describes a sensor assembly that includes a cylindrical housing defining an interior; a cartridge sub-assembly housed in the interior of the housing, the cartridge sub-assembly comprising a sensor element, a first printed circuit board (PCB) securing the sensor element in a holding position, and a first potting sealing the first PCB and the  
10 sensor element in the holding position, the first potting encapsulating the sensor element and forming a water impermeable seal between the sensor element and the first PCB; wherein the cartridge sub-assembly is secured in the interior of the housing by a second potting.

According to a further aspect, this disclosure describes a sensor assembly that  
15 includes a cylindrical housing defining an interior, a cartridge sub-assembly housed in the interior, the cartridge sub-assembly comprising a sensor element, a first printed circuit board (PCB) securing the sensor element in position, and a first potting sealing the first PCB and the sensor element in the position. The cartridge sub-assembly is secured in the interior by a second potting, the first PCB  
20 comprises a first cut-out portion defining the holding position. The sub-assembly further includes a second PCB mounted to the first PCB in an orthogonal locking relationship, the second PCB comprising a second cut-out portion defining the holding position, wherein each the first cut-out portion and the second cut-out portion define a plurality of holding positions for securing a plurality of the sensor  
25 elements.

According to another example aspect, a sensor assembly is described that includes a housing defining an interior, having a first open-end and a second open-end; a cartridge sub-assembly housed in the interior, the cartridge sub-assembly comprising a sensor element, a first printed circuit board (PCB) securing the sensor  
30 element in a position, and a first potting sealing the first PCB and the sensor element in the position, wherein the cartridge sub-assembly is secured in the

interior by a second potting. A first end-cap is secured to the first open-end and a second end-cap secured to the second open-end of the cylindrical housing, wherein the each of the open-ends receives a cable, and wherein each of the end-caps is secured to the cable using an overmolded layer.

5 According to another example aspect, an array of sensor assemblies is described. The array includes a plurality of sensor assemblies that each include: (i) a housing defining an interior; (ii) a cartridge sub-assembly housed in the interior, the cartridge sub-assembly comprising a sensor element, a first printed circuit board (PCB) securing the sensor element in a position, and a first potting sealing the first  
10 PCB and the sensor element in the position, wherein the cartridge sub-assembly is secured in the interior by a second potting. A cable is received by the cylindrical housing of each of the sensor assemblies, the cable having a jacket and a plurality of wires secured in the jacket, wherein a wire of the plurality of wires is exposed from the jacket in each of the sensor assemblies and coupled to the sensor  
15 element.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

Reference will now be made, by way of example, to the accompanying drawings which show example embodiments of the present application, and in which:

Figure 1 is a perspective view of a cartridge sub-assembly of a sealed sensor  
20 assembly according to example embodiments;

Figure 2 is a plan view illustrating a sensor assembly using the cartridge sub-assembly of Figure 1 according to example embodiments;

Figure 3 is a further perspective view of the cartridge sub-assembly;

Figure 4A illustrates terminals of a PCB used in the cartridge sub-assembly of  
25 Figure 1 according to example embodiments; and

Figure 4B illustrates a housing and potted PCB boards of a cartridge sub-assembly of the sensor assembly.

Similar reference numerals may have been used in different figures to denote similar components.

## **DETAILED DESCRIPTION**

5

With the increased dependency placed upon micro-seismic analysis when extracting minerals, there is an ever-increasing need for multiple sensor arrays offering improved signal fidelity, as well as an ever-increasing need for improved sensor array reliability and durability when operating under severe pressure, temperature and environmental conditions.

10

The present document describes the design and manufacturing method for producing a multiple sensor array which fills the need for increased fidelity, reliability and durability. Emphasis is placed upon the innovative design and production of sub-assemblies whose performance and durability can be pre-qualified prior to final assembly and shipment for deployment.

15

### **"Sensor Cartridge" Sub-Assembly:**

A novel sub-assembly design and manufacturing process ensures that the modular sub-assembly (10), dubbed the "sensor cartridge" (10), has complete standalone functionality, and can pass a rigorous quality control procedure which features a check for hydrostatic pressure-resistance through pressurization as well as checks for the quality and fidelity of the sensor signal by running proprietary sensor excitation and response analysis. Because the sub-assembly is complete in its functionality, the above quality control checks guarantee complete end-use functionality of the sensor array prior to its final assembly. Therefore, one of the advantages of this design is that it permits a sensor array which can be over 3000 meters in length to be completely checked for hydrostatic pressure resistance prior to deployment. Due to the cumbersome length of the sensor array, completely checking the final tool array assembly for hydrostatic pressure resistance is impossible.

25

30

Not only was the sub-assembly design chosen to be modular, but it uses, in a novel way, the materials employed to make the "sensor cartridge" (10) subcomponents.

These materials are chosen and treated in such a way that bonding occurs between the individual sub-components which ensures a pressure and temperature resistant encapsulation of the sensor elements. In the preferred embodiment, seen in Fig.1, the encapsulation material (1) of a sub assembly is an epoxy with ceramic additives, and has a glass transition temperature of 105°C, however, other embodiments may use a high temperature epoxy which has a glass transition temperature in the 200°C range. FR4 PCBs (2) and (3) are used as structural elements to hold the sensors elements (4). Because the epoxy will bond to the PCBs (2,3) made from FR4 material if these are treated properly, a pressure-resistant, water impermeable seal will be made between these structural elements and the epoxy encapsulant (1). Moreover, internal traces inside PCBs (2,3) conduct the sensor response signals from inside the encapsulation to the outside of the "cartridge sensor". Because these traces are internal to the FR4 PCB boards, they are physically sealed and prevent water which is under hydrostatic pressure from migrating from outside into the encapsulation, using these electrical traces on the PCBs as conduits to reach the sensor elements. In the preferred embodiment, the sensor elements are geophones (4) which are prone to failure if they become wet.

Other embodiments to this cartridge sensor may include thermistors as sensor-elements and the inclusion of amplifiers in order to provide gain to the sensors signals as they are transmitted to the surface.

In the preferred embodiment, the structural FR4 PCBs (2,3) are designed to lock together and locate the geophone (4) pairs in a mutually orthogonal concentric cylinder. This orthogonality improves accuracy when detecting the source and direction of P-and S-waves because the dip and azimuth of the seismic pulses can be more accurately calculated.

Sub-components (2), (3) and (4) are over-moulded in a split cavity mould. The mould is designed to minimize cavity pressure when injecting epoxy, in order that the sensor elements do not deform or are penetrated by the moulded encapsulant. Subsequent to moulding, the "cartridge sensor" (10) is removed from the mould and post-treated using a heat schedule designed to minimize residual stresses which results from the thermal expansion of the diverse sub-components.

## A) DH Sensor Pod Assembly

Referring to FIG. 2, in the final assembly of the sensor pod (20), the "sensor cartridge" (10) is positioned along a length of seismic cable (21) at the desired location for the sensor pod. Three twisted-pair conductors (9) are cut and attached to the three terminals on the "cartridge sensor" PCB (2,3). Each terminal corresponds to one of 3 seismic channels inside the pod. The remaining twisted pairs in the seismic cable (21) are tied to along the length of the "cartridge sensor" (10) . These remaining seismic twisted pairs pass through the pod (20) to consecutive sensor pods lower down in the array. This corresponds to item (21), seen in Fig.2, which discloses an example DH Pod Assembly (20) with "Cartridge Sensory" Sub-Assembly (10). A stainless steel sleeve, (11) in Fig. 2, is placed over the "cartridge sensor" (10) and the pass-through seismic cable (21). End-caps, (24) in Fig.2, are fed over the seismic cable 21 and attached to the stainless steel sleeve. These end-caps are in-turn overmoulded, (25) in Fig (2), using polyurethane, to the seismic cable (21), providing a watertight bond. Because the primary wartertight seal is created at the "cartridge sensor" sub-assembly (10) , external seals for the sensor pods (20), created by using o-rings to seal the end-caps to the stainless steel sleeve and by using an overmould to seal the end-caps to the seismic cable, are redundant, secondary seals.

Any voids which are formed inside the pod housing (11) and the "cartridge sensor" (10) are filled with the same encapsulant material (22) used to mould the cartridge sub-assembly. In this way, good transmissibility of seismic events is ensured from the outside of the sensor pod, through the "cartridge sensor", into the sensor elements.

The design disclosed herein describes a cartridge sub-assembly (10) which acts as a primary seal for the sensor elements, while the external pod housing (11) performs the function of a secondary seal. Unlike the design presently disclosed, Havig et al. does not describe a modular sub-assembly which is standalone, complete in its functionality and which can be pre-qualified or tested in order to guarantee the final end-use functionality of the entire sensor array prior to final assembly. Moreover, unlike Havig et al, the disclosed design features a structure in which all sensor elements are concentric.

Berg et al. and Knaack et al. describe multiple sensor arrays for deployment in a well bore, but the sensor elements are hydrophones instead of geophones, and the sensor signal transmitted to the surface is digital instead of analog. Moreover, the primary sealing of the pods in both cases is performed at the sensor housing.

5

Accordingly, described herein is an improved downhole (DH) micro-seismic sensor, which features increased performance and reliability. In this design, a new subassembly (10), dubbed the "geophone cartridge" is created prior to the final assembly of the sensor pods (20). The geophone cartridge (10) allows a more controlled epoxy-potting process which offers improved sealing, increased impact resistance, and which resists the development of cracks in the cartridge assembly. Moreover the cartridge assembly makes possible, the pressure testing of 100% of the micro-seismic sensors prior to customer delivery. This step makes the DH tool manufacturing process more rigorous and is designed to offer improved reliability for deployment at depth under hydrostatic pressure. See Figures 3, 4A and 4B.

15

The PCB boards (2,3) were chosen as a structural member to contain the geophones (4), because of the well-known adhesion of epoxy potting (1) compounds to these boards. The adhesion creates a primary seal between the geophones (4) and the external hydrostatic pressure from the well. In the final assembly, a secondary seal is created when the cartridge (10) is inserted into the stainless steel pod housing (11) which has end-caps (24) which are over-moulded onto the polyurethane jacket. In order to fix the cartridge within the housing (11), a second epoxy potting (22) is done to surround the cartridge (10) in the housing (11). In the primary seal created by the "geophone cartridge" (10), water cannot migrate from the outside of the board, along the electrical conductors to the geophones (4) because the electrical conductors (9) which lead from the geophones (4) to the edge of the PCB board (2, 3) are embedded and are concealed. The PCB boards (2, 3) also have a strain relief attachment (8) for the micro-seismic cables. In this way the risks of breaking the electrical connections to the geophones (4) due to impact are mitigated.

20

25

30

In the secondary seal, when epoxy (22) is potted over the cartridge (10) inside the stainless steel tube housing (11), the individual twisted pairs which are connected to the

cartridge (10) have epoxied sections of magnet wire (9) which are strain-relieved by the PCB board.

5 Epoxy bonds well to magnet wire and as such, a block is created which eliminates the potential for water to migrate from the twisted pairs into the cartridge.

In order to mould the geophone cartridge, the inventors tested and verified the performance of many epoxy potting compounds. The final selection was made based on the epoxy's tensile strength, its low moisture absorption, its temperature stability, its impact resistance as well as its low shrinkage during moulding.

10

During the moulding process, the moulding parameters of temperature and humidity can be better controlled in an enclosed chamber, because the cartridge is moulded as a standalone unit, free of the sensor housing and the associated seismic cable. The shot fill is better assured because of the improved benefits of a dedicated mould which has better venting and optimal location of the injection gates. This validated potting process will ensure that there are no air-bubbles trapped within the potting which can create a conduit for water to migrate through in the event that the secondary seal is breached.

15

Moreover, once moulded, the cartridge (10) can be inspected and tested as a standalone unit free of the external stainless steel housing (11). Visual inspection can be made for air bubbles and cracks due to mould shrinkage. As a second step in the quality control procedure, pressure testing can be done on 100% of the cartridges, and each unit can be checked for electrical resistance, sensitivity and frequency response after pressure testing.

20

25

These added controls to the manufacturing of DH tools enable a sensor pod which has redundant sealing, and is more robust against impact, crushing and thermal cycling. The perpendicularity of the PCB boards assures not only improved orthogonality of the sensor signals, but also ensures that the geophones are surrounded by a uniform and controlled amount of impact resistant epoxy. In this way resistance to impact and crushing is better assured. Moreover mould shrinkage can be better controlled, because of the improved moulding process, which thus eliminates residual stresses and better resists the development of cracking in the encapsulation. The sensor will better resist

30

impact and thermal cycling when under hydrostatic pressure, since it is devoid of cracks in the encapsulation.

5 Through the adoption of the geophone cartridge sub-assembly, the presently described embodiments mitigate the risks associated with the common failure modes for DH sensor arrays, which include (1) breach of the seals (2) breaks in the electrical connections to the geophones, (3) cracks developing due to thermal cycling (4) loss of operation of the geophones due to impact

Claims:

1. A sensor assembly comprising:

a cylindrical housing defining an interior;

a cartridge sub-assembly housed in the interior of the housing, the cartridge sub-assembly comprising a sensor element, a first printed circuit board (PCB) securing the sensor element in a holding position, and a first potting sealing the first PCB and the sensor element in the holding position, the first potting encapsulating the sensor element and forming a water impermeable seal between the sensor element and the first PCB;

wherein the cartridge sub-assembly is secured in the interior of the housing by a second potting.

2. The sensor assembly of claim 1, wherein the first PCB comprises a first cut-out portion defining the holding position.

3. The sensor assembly of claim 2, further comprising a second PCB mounted to the first PCB in an orthogonal locking relationship, the second PCB comprising a second cut-out portion defining the holding position, wherein each the first cut-out portion and the second cut-out portion define a plurality of holding positions for securing a plurality of the sensor elements.

4. The sensor assembly of claim 1, wherein the first PCB comprises a terminal positioned at an end of the first PCB that extends beyond the first potting for connecting the first PCB to a wire, the wire being electrically coupled to the sensor element by a conductive signal trace in the first PCB, wherein the conductive signal trace transmits signals from the sensor element within the first potting to the terminal outside of the first potting.

5. The sensor assembly of claim 4, wherein the cylindrical housing further comprises a first open-end and a second open-end, the first open-end receiving a cable having a jacket and a plurality of wires secured in the jacket.

6. The sensor assembly of claim 1, wherein the cylindrical housing further comprises a first open-end and a second open-end and further comprising a first end-cap secured to the first end and a second end-cap secured to the second end.

7. The sensor assembly of claim 6, wherein the each of the open-ends receives a cable, and wherein each of the end-caps is secured to the cable using an overmolded layer.

8. An array of sensor assemblies as claimed in claim 1, the array comprising:

a cable being received by the cylindrical housing of each of the sensor assemblies, a portion of the cable being secured in the cylindrical housing of each sensor assembly by a potting; and

the cable having a jacket and a plurality of wires secured in the jacket, wherein a wire of the plurality of wires is exposed from the jacket in each of the sensor assemblies and coupled to the sensor element.

9. The array of sensor assemblies of claim 8, wherein each sensor assembly further comprises a first end-cap and a second end-cap, the first and second end-caps being secured to the cylindrical housing and the cable.

10. The array of sensor assemblies of claim 9, wherein each of the end-caps is secured to the cable using an overmolded layer.

11. A sensor assembly comprising:

a cylindrical housing defining an interior;

a cartridge sub-assembly housed in the interior, the cartridge sub-assembly comprising a sensor element, a first printed circuit board (PCB) securing the sensor element in position, and a first potting sealing the first PCB and the sensor element in the position;

wherein the cartridge sub-assembly is secured in the interior by a second potting;

wherein the first PCB comprises a first cut-out portion defining the holding position; and

further comprising a second PCB mounted to the first PCB in an orthogonal locking relationship, the second PCB comprising a second cut-out portion defining the holding position, wherein each the first cut-out portion and the second cut-out portion define a plurality of holding positions for securing a plurality of the sensor elements.

12. A sensor assembly comprising:

a housing defining an interior, having a first open-end and a second open-end;

a cartridge sub-assembly housed in the interior, the cartridge sub-assembly comprising a sensor element, a first printed circuit board (PCB) securing the sensor element in a position, and a first potting sealing the first PCB and the sensor element in the position, wherein the cartridge sub-assembly is secured in the interior by a second potting;

a first end-cap secured to the first open-end and a second end-cap secured to the second open-end of the cylindrical housing, wherein the each of the open-ends receives a cable, and wherein each of the end-caps is secured to the cable using an overmolded layer.

13. An array of sensor assemblies, the array comprising:

a plurality of sensor assemblies each comprising: (i) a housing defining an interior; (ii) a cartridge sub-assembly housed in the interior, the cartridge sub-assembly comprising a sensor element, a first printed circuit board (PCB) securing the sensor element in a position, and a first potting sealing the first PCB and the sensor element in the position, wherein the cartridge sub-assembly is secured in the interior by a second potting;

a cable being received by the cylindrical housing of each of the sensor assemblies; and

the cable having a jacket and a plurality of wires secured in the jacket, wherein a wire of the plurality of wires is exposed from the jacket in each of the sensor assemblies and coupled to the sensor element.

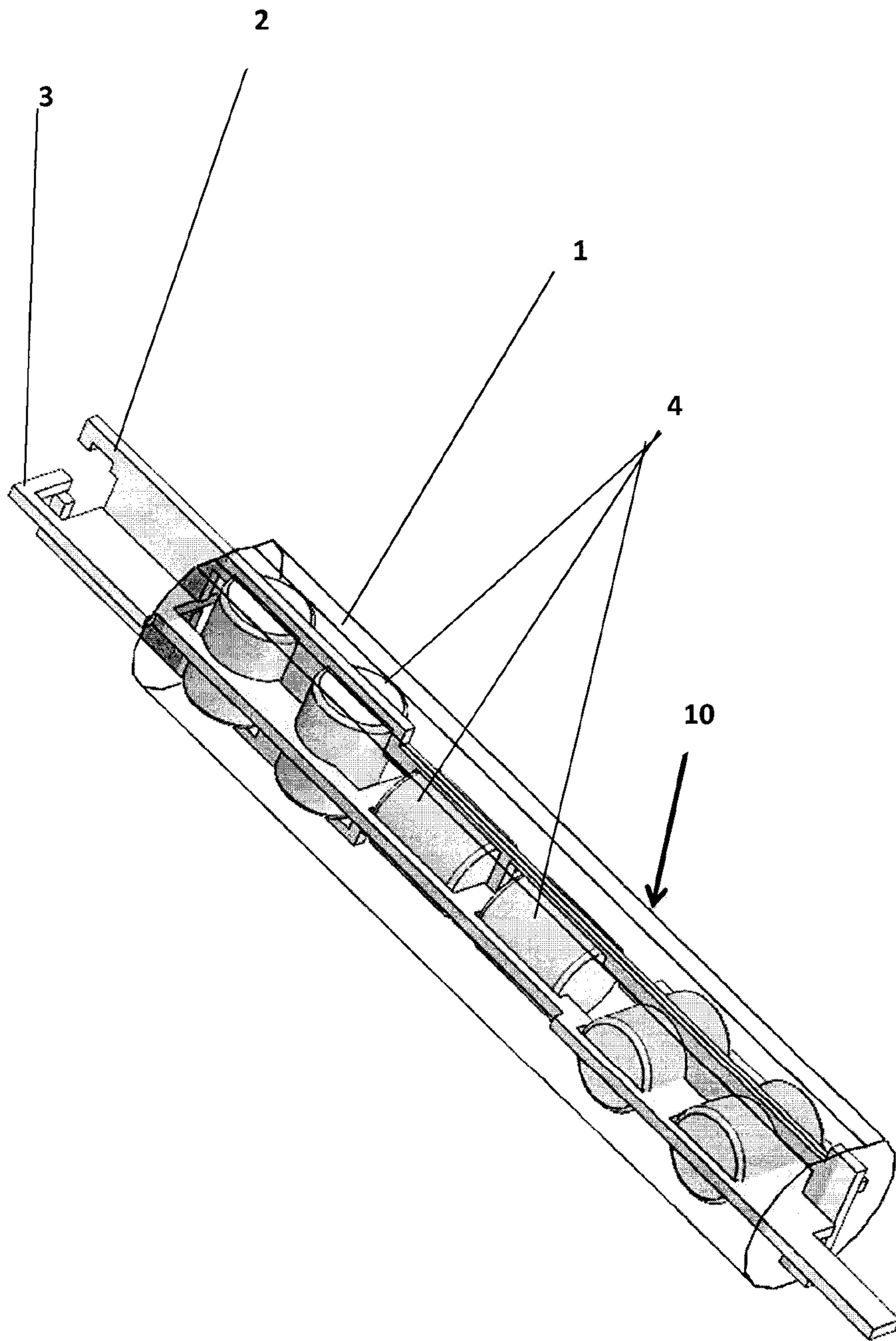


FIGURE 1

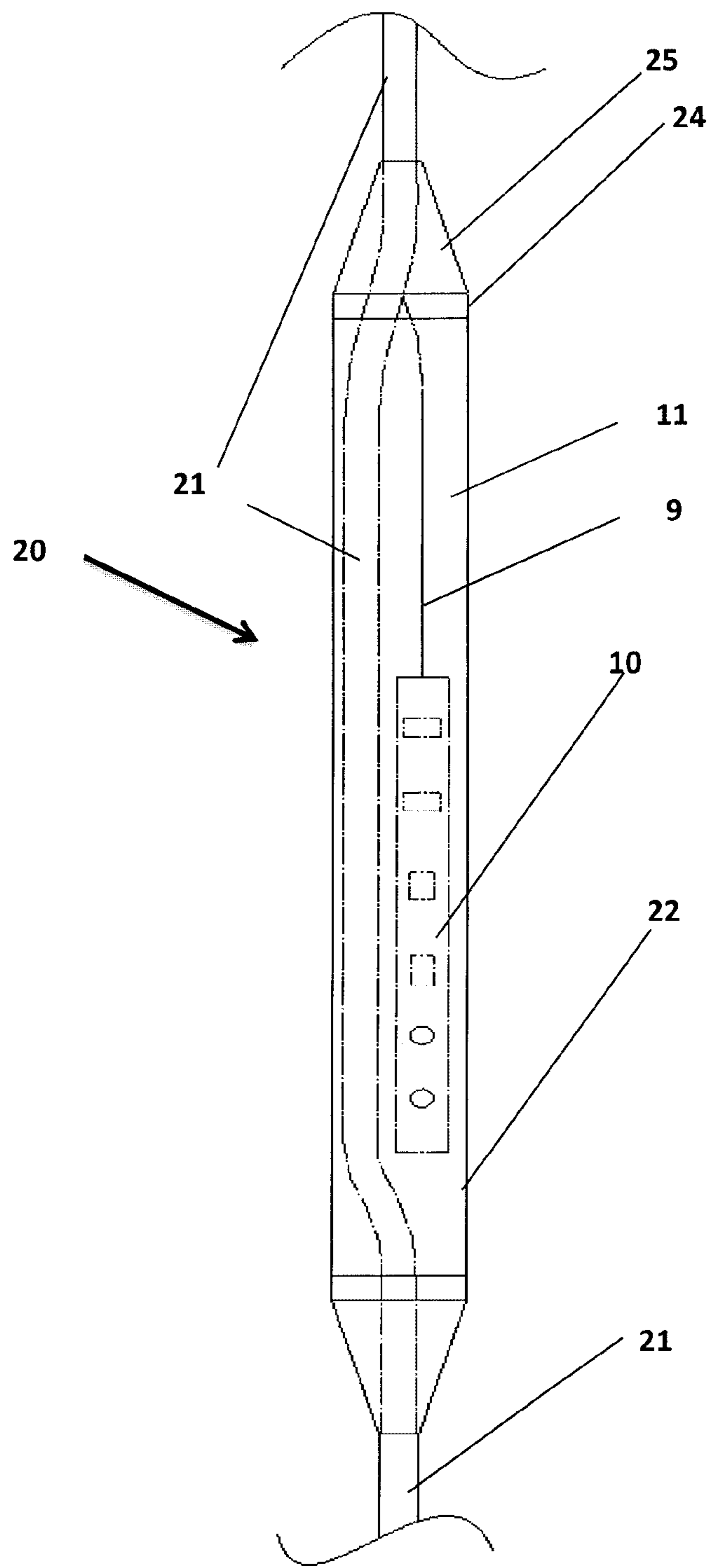


FIGURE 2

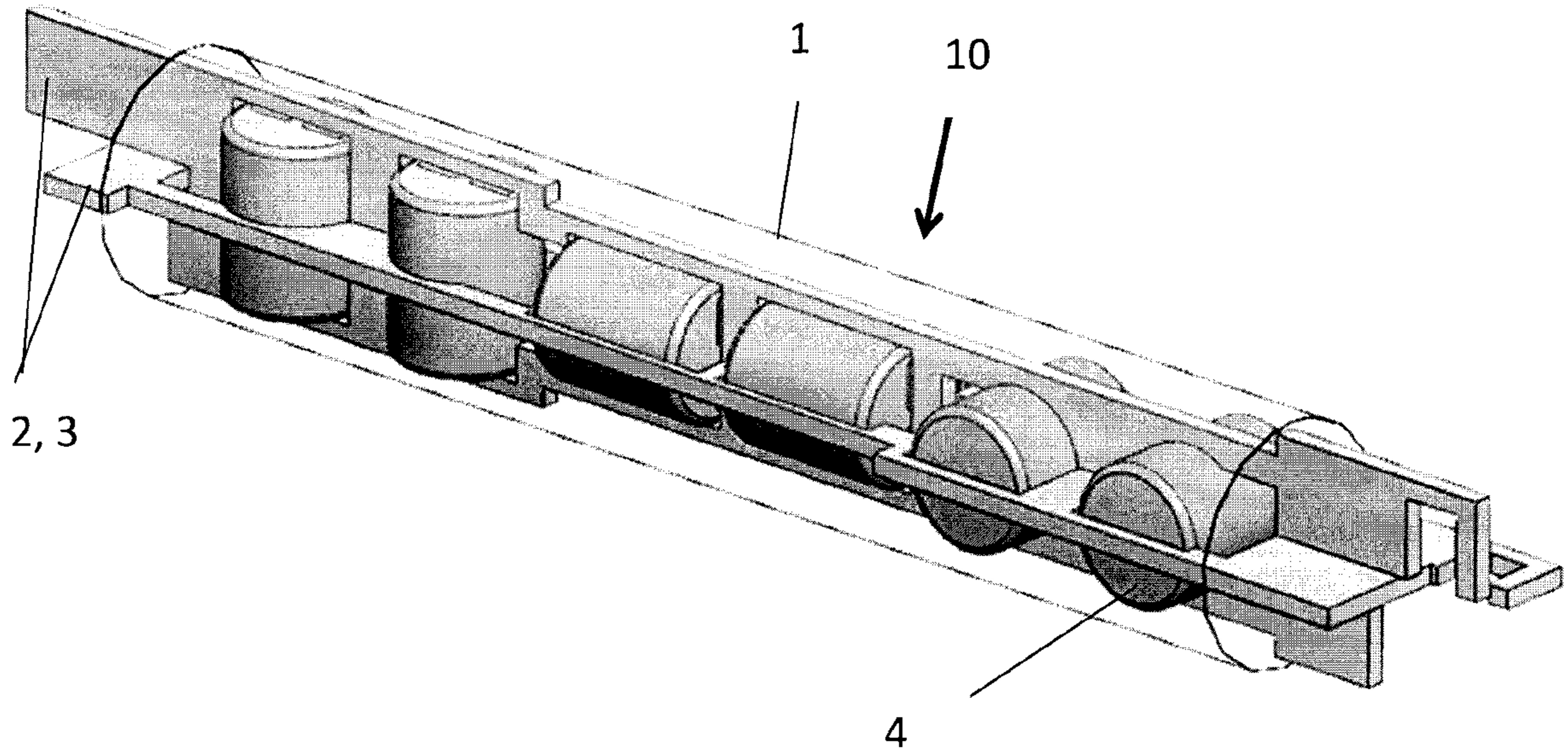
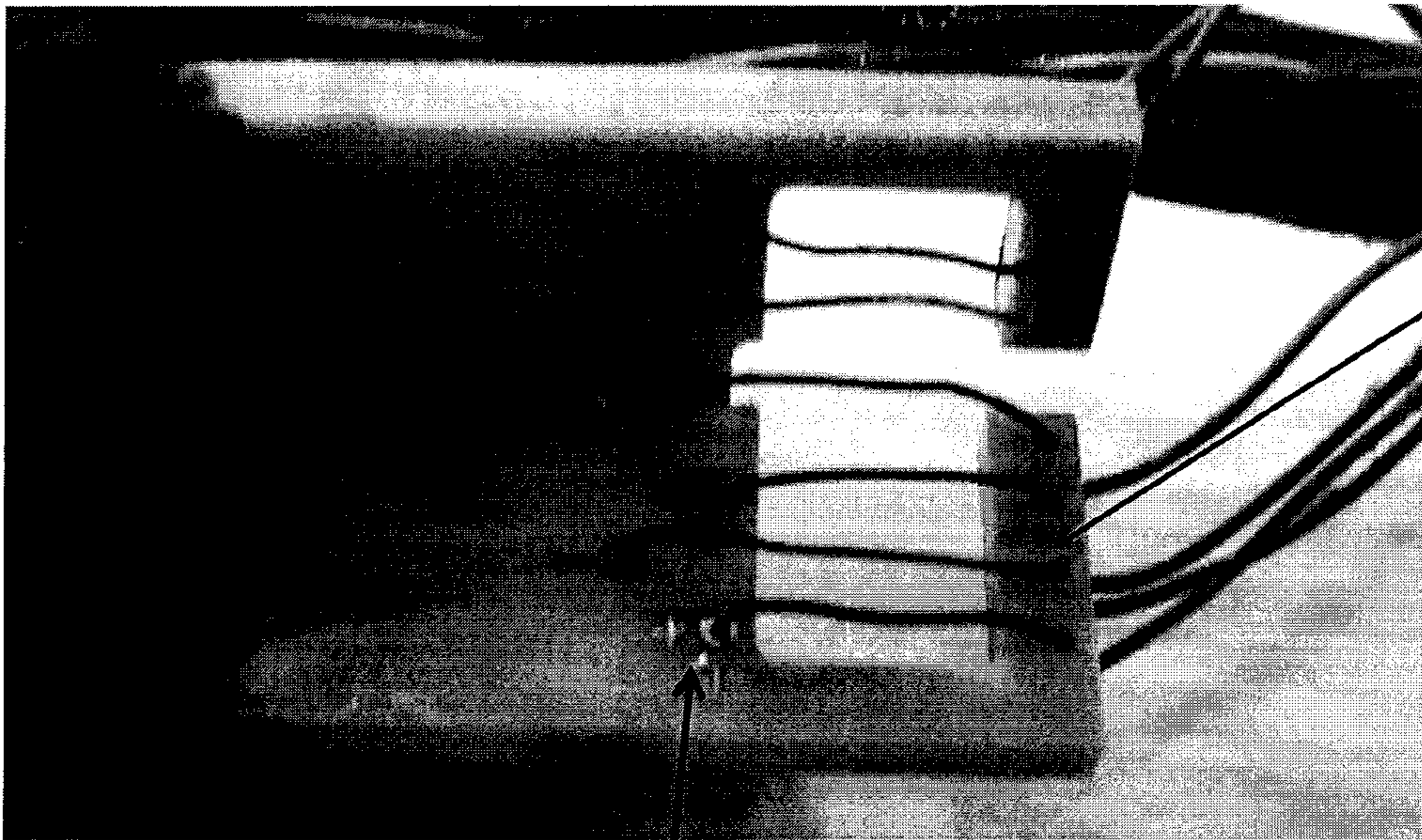


FIGURE 3



9

FIGURE 4A

8

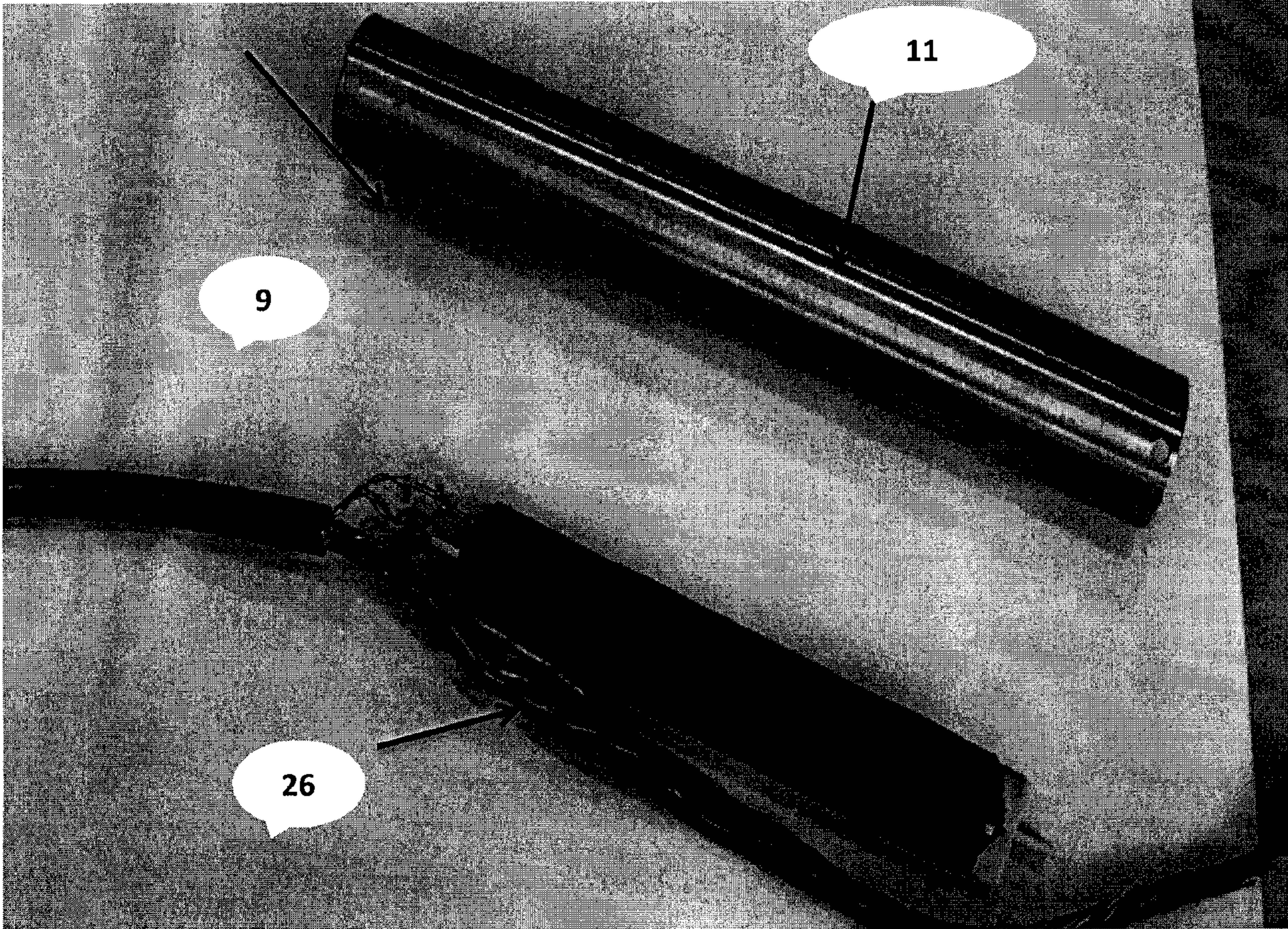


FIGURE 4B

