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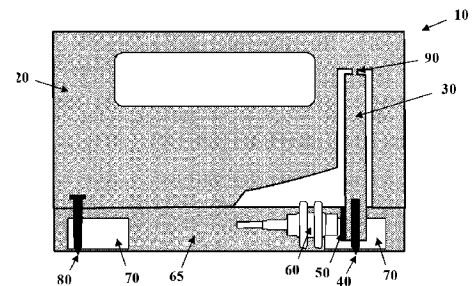
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(54) Title **STRAIN SENSOR**

(57) Abstract

A sensor 10 for measuring strain along a structure, comprising a sensor frame 20 holding a sensor element 30, where one edge of the sensor element 30 is connected to the sensor frame 20 and the other edges are unconnected from the sensor frame 20 thereby enabling deflection of the sensor element 30 relative to the sensor frame 20. A first spike 40 is connected to the sensor element 30. The sensor further comprises a sensor target 50 and a displacement sensor 60, which is directed at the sensor target 50 for detecting displacement of the sensor element 30. At least one second spike 80 connected to a sensor base 65. The first and second spikes 40, 80 are made with a length enabling them to protrude from the sensor base 65 and to engage with the structure to be measured, and where the first spike 40 is running through the sensor base 65 without being in contact with it.



Field of the invention

The invention relates to a sensor, and more specifically to a sensor for measuring strain along a structure. The measurement principle is based on measuring displacement of a sensor element held by a sensor frame.

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Background

The present invention relates to measurement of strain along a structure in an efficient, flexible and cost efficient way.

10 Prior art methods and sensors for determining strain are primarily based on strain gauges placed directly on a structure to be measured. Installing and replacements of such sensors often requires extensive effort, and the sensors will normally have to be installed on a structure prior to installing the structure subsea. Strain gauges are further vulnerable to harsh subsea environment. They should therefore be sealed prior to a subsea installation.

15 US 2011/0259115 A1 shows examples of strain gauges for structural load monitoring using collars and connecting elements with strain sensors. Different configurations of strain gauges are disclosed. Strain gauges are however not very accurate and unable to measure very small values of strain.

20 Other devices and methods for measuring strain of a structure are fixing flanges to a structure and measuring the distance between the flanges.

US 2015211968 A1 describes another type of sensor for measuring displacement. The sensing element is based on a crystalline material, such as sapphire or quartz. Fig. 5 shows the displacement sensor attached to a pipe, and Fig. 9-2 shows how bending of the sensing element is affected by bending of the pipe it is connected to.
25 The sensor element will be more sensitive to bending than displacement. Even though this solution is an improvement compared to using strain gauges for measuring strain, it will not be able to measure very small displacement values.

There is a need for a flexible sensor for measuring very small values, in the range of micro-meter and nano-meter, of strain along a structure it is connected to.

30 The present invention provides compact sensor for measuring and monitoring strain along a structure. It will lock to the structure when held close to it and will then be operable without further installation. It can thus be easily connected to or be removed from a structure either manually, or by means of a ROV.

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Short description of the invention

The present invention provides a very sensitive and compact sensor for detecting very small displacement values of a structure that it is connected to.

5 The invention comprises a sensor for measuring strain along a structure. The sensor comprising,

- a sensor frame holding a sensor element, where one edge of the sensor element is connected to the sensor frame and the other edges are unconnected from the sensor frame thereby enabling deflection of the sensor element relative to the sensor frame;
- 10 - a first spike connected to the sensor element;
- a sensor target and a displacement sensor directed at the sensor target for detecting displacement of the sensor element;
- at least one second spike connected to a sensor base, and where
- 15 - said first and second spikes are made with a length enabling them to protrude from the sensor base and to engage with the structure to be measured, and where the first spike is running through the sensor base without being in contact with it.

Further features of the sensor are defined in the dependent claims.

20 The invention is further defined by a method for measuring strain along a structure, comprising:

- placing a sensor on the structure, said sensor comprises a sensor frame holding a deflectable sensor element, a first spike connected to the sensor element, and the at least one second spike connected to the sensor frame, a sensor target and a displacement sensor;
- 25 - locking the sensor to the structure by means of at least one connection magnet thereby forcing the spikes against the structure to be measured;
- detecting displacement between the first and second spikes by means of the displacement sensor directed at the sensor target.

Further features of the method are defined in the dependent claims.

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Detailed description of the invention

The invention will now be described in detail with reference to the drawings illustrating different embodiments:

5 Figure 1 illustrates conceptual features of a strain sensor according to the invention;
 Figure 2 illustrates one embodiment of the main components of the strain sensor;
 Figure 3 illustrates parts comprised in a complete assembly of the strain sensor, and
 Figure 4 illustrates a complete assembled strain sensor.

10 The purpose of the present invention is to provide a compact strain sensor that is
 able to measure very small displacement values, i.e. in the order of nano-meter, and
 where the sensor can be easily installed and removed from subsea installations and
 structures it is connected to. The sensor is operative for measuring as soon as it is
 snapped to, and connected to a structure either manually or by means of a ROV.

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The following reference numbers are used in the disclosure:

	10 – strain sensor
	20 – sensor frame
20	30 – sensor element
	40 – first spike
	50 – sensor target
	60 – displacement sensor
	65 – sensor base
25	70 – connection magnet
	75 – cavity
	80 – second spike
	85 – detection electronics etc.
	90 – weak link
30	95 – screw hole
	100 – housing
	105 – upper sealing recess
	110 – connector
	115 – lower sealing recess
35	120 – grip

Figure 1 shows the conceptual features of the inventive strain sensor 10 for measuring strain along a structure. The sensor comprises a frame 20 holding a sensor element 30. One edge of the sensor element 30 is connected to the sensor

frame 20 and the other edges are unconnected from the sensor frame 20 thereby enabling deflection of the sensor element 30 relative to the sensor frame 20.

The connection between the sensor element 30 and the sensor frame 20 is preferably a weak link 90 enabling the sensor element 30 to deflect when exposed to strain
5 relative to the sensor frame 20.

In one embodiment of the invention, the sensor element 30 is beam shaped and stiff, and made from one and same part as the sensor frame 20. The weak link 90 can then be made by milling out some of the material between the sensor frame 20 and the sensor element 30, as shown in figure 1.

10 Other shapes of the sensor element 30 are also feasible as long as it has deflecting properties relative to the sensor frame 20. The deflecting properties in one embodiment can be provided by a weak link 90, which is a movable coupling or joint between the sensor frame 20 and the sensor element 30. In this case, the sensor frame 20 and the sensor element 30 can be made in different materials.

15 In one embodiment of the sensor 10, the material of the sensor frame 20 is Polyether Ether Ketone, PEEK, which is a polymer with high mechanical and chemical resistance providing the sensor frame 20 with robust properties. This will also provide a strong and stiff sensor element 30 when made in one and same part as the frame 20.

20 A first spike 40 is connected to the sensor element 30. This spike is preferably connected at a far end of the sensor element 30 relative to the weak link 90.

At least one second spike 80 is connected to a sensor base 65, which is firmly fixed to the sensor frame 20. In one embodiment, two spikes spaced apart are connected to the sensor base 65 for better stability of the sensor 10 when connected to a
25 structure to be measured.

The first and second spikes 40, 80 are made with a length enabling them to protrude from the sensor base 65 enabling the spikes to engage with a structure to be measured. The first spike 40 is running through the sensor base 65 without being in contact with it. By letting the first spike 40 be unconnected from the sensor base, it
30 is freely movable relative to the at least one second spike 80 connected to the sensor base 65. Figure 1 illustrates how the spikes protrude from the sensor base 65 enabling them to engage with a structure to be measured.

In one embodiment of the invention, the first spike 40 and the at least one second spike 80 are located near each opposite ends of the sensor frame 20 as illustrated in
35 figure 1. The sensitivity of the sensor 10 will increase proportionally to the distance between the fixed and the flexible pins, i.e. the first and the second spikes 40, 80.

The spikes are preferably made sharp and in a hard material, e.g. HSS steel. Such that they get a firm grip and engagement with the structure to be monitored or measured.

According to the invention, a sensor target 50 and a displacement sensor 60 directed at the sensor target 50 are arranged for detecting displacement of the sensor element 30.

In one embodiment, the sensor target 50 is connected to the sensor element 30 and the displacement sensor 60 is connected to the sensor frame 20.

In another embodiment, the sensor target 50 is connected to the sensor frame 20 and the displacement sensor 60 is connected to the sensor element 30.

In one embodiment of the invention, the sensor target 50 is a metal plate, and the displacement sensor 60 is a magnetic field sensor or a capacitance sensor.

In another embodiment, the sensor target 50 is a reflection surface, and the displacement sensor 60 is an optical sensor, e.g. an optical short-range distance sensor.

In figure 1, the sensor base 65 is fixed normal to the sensor frame 20 as illustrated, representing one embodiment of the invention.

Figure 2 illustrates another embodiment with the main components of the strain sensor. In this embodiment, the sensor base 65 of the sensor 10 is fixed parallel to the sensor frame 20 when the sensor 10 is assembled and operative.

In one embodiment of the invention, the sensor 10 comprises at least one connection magnet 70 mounted in the sensor base 65. The purpose of this is connecting the sensor 10 to a structure having magnetic properties. The at least one connection magnet 70 is preferably mounted in a cavity 75 in the sensor base 65. This configuration will provide protection from harsh environments. Figure 2 shows an embodiment of the invention where five magnets are used. By increasing the number of magnets, the spikes 40, 80 will be provided with a stronger force for engaging with the structure that the sensor 10 is locked to.

When the sensor 10 is being used in environments such as water, the sensor 10 is preferably protected by a casing.

Figure 3 illustrates the sensor 10 enclosed within a casing and the parts comprised in a complete assembly of the strain sensor 10, while Figure 4 illustrates a complete assembled strain sensor according to an embodiment of the invention.

A fully assembled sensor 10 comprises a housing 100 for protection. The housing can for instance be made of a hard plastic material. The housing 100 and the sensor base 65 make a complete closed casing for the sensor frame 20 and the sensor element 30 when assembled by means of tightening screws inserted in screw holes 95 matched in the housing 100, the sensor frame 20 and the sensor base 65.

In order to provide a watertight sealing between the housing 100, the sensor frame 20 and the sensor base 65, the sensor frame 20 comprises an upper sealing recess 105 and a lower sealing recess 115 for holding seals providing sealing between the sensor frame 20, the housing 100 and the sensor base 65. As mentioned, the sensor is connected to a structure to be monitored by means of the magnets 70. If necessary, the sensor 10 can further be fastened to a structure to be monitored by means of at least one fastening strap.

As shown in the embodiments of the sensor 10 illustrated in figures 2 and 4, two second spikes 80 are connected to the sensor base 65. When the sensor base is fixed to the sensor frame 20, by means of screws via the screw holes 95, the spikes 80 will hold the sensor base 20 stationary relative to the first spike 40 connected to the sensor element 30.

The second spikes 80, can in another embodiment of the invention, be directly connected to the sensor frame 20 and run through the sensor base. This configuration will avoid possible slipping between the sensor base 65 and the sensor frame 20. Holes in the sensor base 65 where the spikes are running through can then be provided with O-rings for tightening and protecting against water break-through. O-rings can also be used in the hole of the sensor base 65 where the first spike 40 is running through. This O-ring should however not be too firm since the first spike 40 is connected to the deflecting sensor element 30 enabling the strain measurements.

In order to detect displacement, the sensor 10 further comprises detection electronics 85 connected to the displacement sensor 60. Measured displacement values is in one embodiment logged by means of electronics connected to the detection electronics 85.

In another embodiment, measured values are transmitted to an external device either wirelessly or by wire. In either case, the sensor assembly then further comprises transmission electronics connected to the detection electronics 85.

If signals are transmitted by wire, a bushing or connector 110 is mounted on the housing 100 as shown in figure 3. This will ensure that signals from the displacement sensor 60 can be lead through the housing while avoiding penetration of water into the housing 100.

The present invention further comprises a method for measuring strain along a structure.

The method comprises a first step of placing a sensor 10 on the structure, said sensor 10 comprises a sensor frame 20 holding a deflectable sensor element 30, a first spike 40 connected to the sensor element 30, and at least one second spike 80 connected to the sensor frame 20, a sensor target 50 and a displacement sensor 60;

The next step is locking the sensor 10 to the structure by means of at least one connection magnet 70 thereby forcing the spikes 40, 80 against the structure to be measured.

5 When the sensor 10 is being used in environments such as water, the sensor 10 is in one fully assembled embodiment protected by a casing. The sensor can then be used for monitoring installations by connecting it to subsea structures, e.g. BPO. Due to the small size and mobility of the sensor 10, this can be done by means of a ROV.

10 The last step is detecting displacement between the first and second spikes 40, 80 by means of a displacement sensor 60 directed at the sensor target 50. Strain measurements are then detected and logged by means of detection electronics comprised in the sensor 10 assembly.

In another embodiment of the method, strain measurements are transmitted to an external recording device. This is useful for collecting measurements from several sensors 10 placed on different devices of an installation.

15 In yet another embodiment of the invention, measured displacement values are both logged by means of electronics comprised in the sensor assembly as well as transmitted to an external device.

The following is an example of a sensor according to the invention, where the type of displacement sensor 60 used is an Eddy current sensor.

20 By using four magnets, each pulling 16 kg with no air-gap, a total force of 25 kg with 1.6 mm gap is achieved. Three steel pins of HSS steel used. The displacement sensor 60 is an Eddy current sensor (from Micro-Epsilon). The measurement range is 0.3 to 3mm and with an Eddy Current resolution of 0.15 μm . The Sensitivity Scale Factor of the sensor according to the invention is then 9.16 $\mu\text{Strain}/\mu\text{m}$ giving
25 an expected strain resolution of 1.4 μStrain , and flexible pin bending resistance of 0.4N @ 250 μStrain .

30 The present invention provides a sensor 10 made for measuring very small values of strain. The sensor 10 is easily mounted to a device or structure to be measured or monitored. By positioning the sensor 10 close to the structure, the sensor will connect to it and the spikes of the sensor 10 is driven into the structure thereby providing a firm grip. The constructional features of the sensor enables measurements of very small strain values, i.e. down to nm and μm .

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CLAIMS

1. A sensor (10) for measuring strain along a structure, comprising,
 - a sensor frame (20) holding a sensor element (30), where one edge of the sensor element (30) is connected to the sensor frame (20) and the other edges are unconnected from the sensor frame (20) thereby enabling deflection of the sensor element (30) relative to the sensor frame (20);
 - a first spike (40) connected to the sensor element (30);
 - a sensor target (50) and a displacement sensor (60) directed at the sensor target (50) for detecting displacement of the sensor element (30);
 - at least one second spike (80) connected to a sensor base (65) fixed to the sensor frame (20);
 - said first and second spikes (40, 80) are made with a length enabling them to protrude from the sensor base (65) and to engage with the structure to be measured, and where the first spike (40) is running through the sensor base (65) without being in contact with it.
2. The sensor (10) according to claim 1, where the connection between the sensor element (30) and the sensor frame (20) is a weak link (90) enabling the sensor element (30) to deflect relative to the sensor frame (20) when exposed to strain.
3. The sensor (10) according to claim 1 or 2, where the sensor element (30) is beam shaped and stiff.
4. The sensor (10) according to claim 1 or 2, where the sensor frame (20) and the flexible sensor element (30) are made from one and same part.
5. The sensor (10) according to any one of the preceding claims, where the material of the sensor frame is Polyether Ether Ketone, PEEK.
6. The sensor (10) according to any one of the preceding claims, where the first spike (40) and the at least one second spike (80) are located near each opposite ends of the sensor frame (20).

7. The sensor (10) according to any one of the preceding claims, where the sensor target (50) is connected to the sensor element (30) and the displacement sensor (60) is connected to the sensor frame (20).
- 5 8. The sensor (10) according to claim 1 or 2, where the sensor target (50) is connected to the sensor frame (20) and the displacement sensor (60) is connected to the sensor element (30).
- 10 9. The sensor (10) according to any one of the preceding claims, where the sensor base (65) is fixed normal to the sensor frame (20).
10. The sensor (10) according to any one of the preceding claims, where the sensor base (65) is fixed parallel to the sensor frame (20).
- 15 11. The sensor (10) according to any one of the preceding claims, comprising two second spikes (80).
12. The sensor (10) according to any one of the claims 1 to 11, where the sensor target (50) is a metal plate, and the displacement sensor (60) is a magnetic field sensor.
- 20 13. The sensor (10) according to any one of the claims 1 to 11, where the sensor target (50) is a metal plate, and the displacement sensor (60) is a capacitance sensor.
- 25 14. The sensor (10) according to any one of the claims 1 to 11, where the sensor target (50) is a reflection surface, and the displacement sensor (60) is an optical sensor.
- 30 15. The sensor (10) according to any one of the preceding claims, comprising at least one connection magnet (70) mounted in the sensor base (65) for connecting the sensor (10) to a structure to be measured.
- 35 16. The sensor (10) according to claim 15, where the at least one connection magnet (70) is mounted in a cavity (75) in the sensor base (65).

17. The sensor (10) according to any one of the preceding claims, comprising at least one fastening strap for connecting the sensor (10) to a structure to be measured.
- 5 18. The sensor (10) according to any one of the preceding claims, further comprising a housing (100) and where the sensor base (65) make a part of the housing (100).
- 10 19. The sensor (10) according to any one of the preceding claims, where the sensor frame (20) further comprises an upper sealing recess (105) and a lower sealing recess (115) for holding seals for providing sealing between the sensor frame (20), the housing (100) and the sensor base (65).
- 15 20. The sensor (10) according to any one of the preceding claims, further comprising detection electronics (85) connected to the displacement sensor (60).
- 20 21. The sensor (10) according to claim 20, further comprising logging electronics connected to the detection electronics (85).
22. The sensor (10) according to claim 20, further comprising transmission electronics connected to the detection electronics (85).
23. Method for measuring strain along a structure, comprising,
- 25 - placing a sensor (10) on the structure, said sensor (10) comprises a sensor frame (20) holding a deflectable sensor element (30), a first spike (40) connected to the sensor element (30), and at least one second spike (80) connected to the sensor frame (20), a sensor target (50) and a displacement sensor (60);
- 30 - locking the sensor (10) to the structure by means of at least one connection magnet (70) thereby forcing the spikes (40, 80) against the structure to be measured;
- detecting displacement between the first and second spikes (40, 80) by means of the displacement sensor (60) directed at the sensor target (50).
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24. The method according to claim 23, by placing the sensor (10) on the structure by means of a ROV.
- 5 25. The method according to claim 23, by logging the strain measurements in detection electronics (85) comprised in the sensor (10).
26. The method according to claim 23, by transmitting the strain measurements to an external recording device.

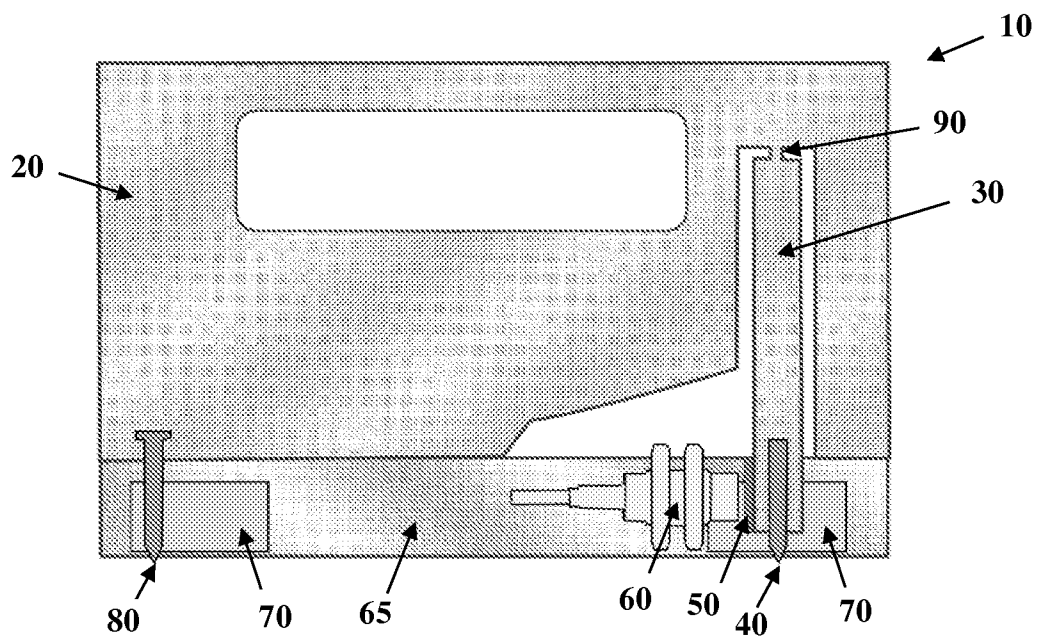


Fig. 1

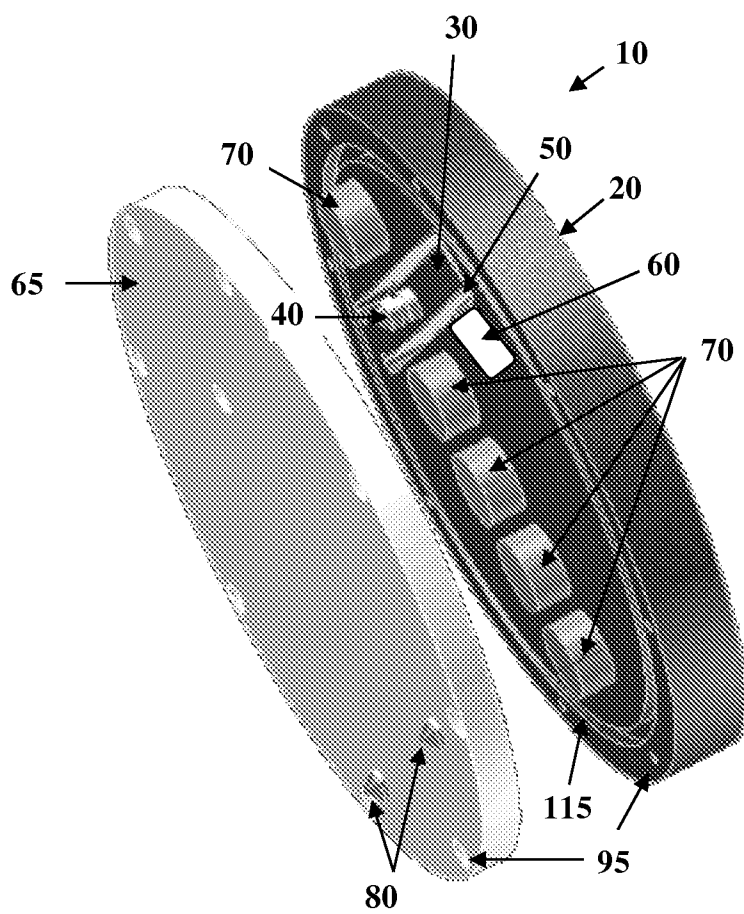


Fig. 2

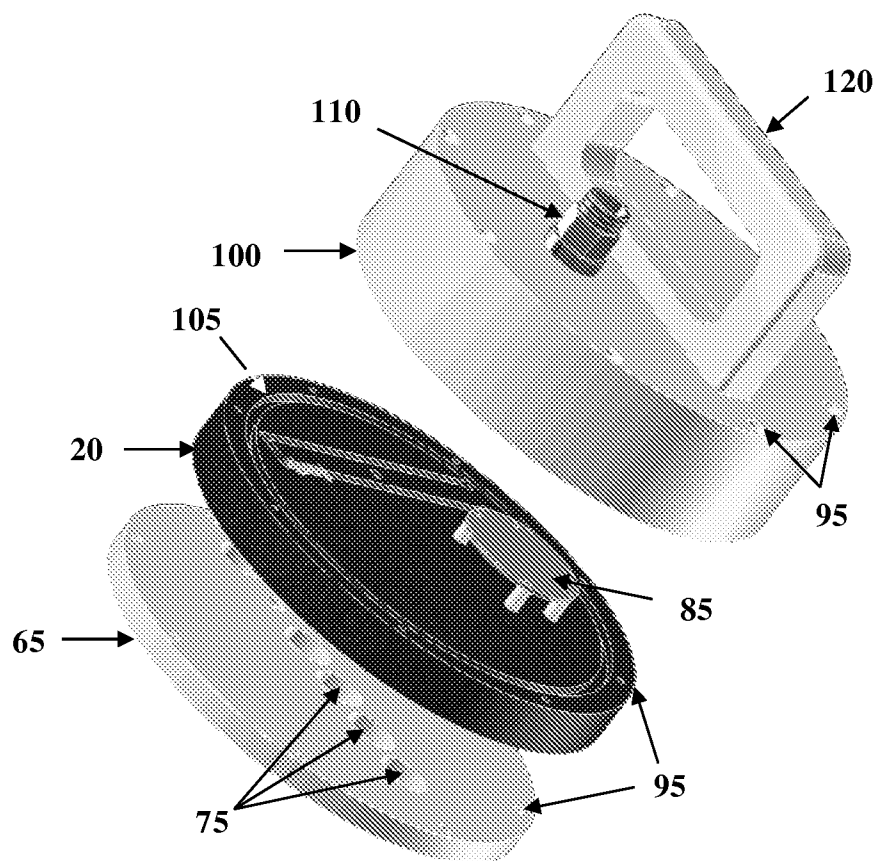


Fig. 3

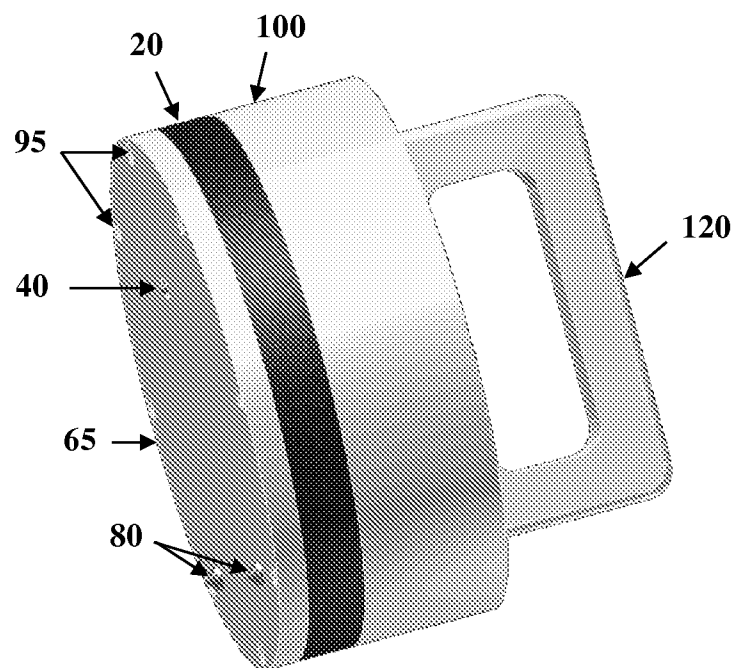


Fig. 4