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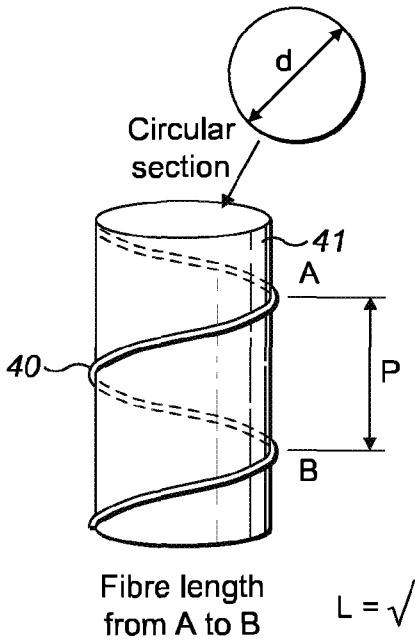
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(54) Title: PARAMETER SENSING AND MONITORING

(57) Abstract: Apparatus and method for monitoring at least one parameter associated with an elongate structure are disclosed. The apparatus may include at least one elongate support body element arranged along a longitudinal structure axis associated with an elongate target structure; and at least one optic fibre element arranged substantially helically along a longitudinal body element axis associated with the at least one support body element. A method of manufacturing flexible pipe body is also disclosed.



$$L = \sqrt{(\pi d)^2 + P^2} \quad \ldots\ldots (1)$$

FIG. 4

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PARAMETER SENSING AND MONITORING

The present invention relates to a method and apparatus for monitoring at least one parameter associated with a structure. In particular, but not exclusively, the present invention relates to a method of monitoring a fibre optic system located on or in a structure to derive data indicative of strain and/or temperature in the structure.

There are many technical fields in which it is useful from time to time or continuously to monitor one or more parameters associated with a structure. For example, from time to time bridges, road surfaces, regions of land, lamp-posts, wind turbine blades, yacht masts, suspended power cables or the like should be repeatedly or continuously monitored so that information identifying any potential problems with the structure can be identified and then remedial action taken.

Another type of structure for which monitoring is desirable is an unbonded flexible pipe of the type used in the oil and gas industry in the field of offshore production. Such flexible pipe includes a length of flexible pipe body terminated at one or more ends with an end fitting. The flexible pipe can be used as a flow-line, riser, jumper or the like. There is an increasing desire to monitor the dynamic behaviour of such pipes. Monitoring strain and/or temperature and/or some other parameter is a way to assess the past, current and/or future performance of the pipe.

In relation to all structures, many different forces will be experienced. This can lead to very complex loads and includes, but is not limited to, self-weight, internal pressure, tension, vortex induced vibration, flexing, twisting or the like.

One way which has been suggested for monitoring parameters associated with such structures is the use of an optical fibre system. The optical fibres can be used as strain gauges, temperature gauges, temperature indicators and strain measurements can be made which are either localised, distributed or semi-distributed depending upon the manner in which the optical fibre is interrogated and regions/sensors in the optical fibre are arranged. WO2009/068907, the disclosure of which is incorporated herein in its entirety, discloses a way in which an optical fibre can be wrapped helically around a flexible pipe and certain measurements taken from which parameters associated with the pipe can be determined.

Whilst such a system does enable certain parameters associated with the pipe to be determined there are limits within which such an optical system can be used. One reason for this is because optical fibres are inherently relatively fragile and if the underlying structure which is being monitored is prone to substantial mechanical movement then mechanical stresses and strains can be induced in the fibre which causes fibre failure.

Therefore, the use of optical fibre has until now been limited to uses where the movement of the optical fibres has been unduly limited.

Also although the method of spirally wrapping an optical fibre around the body of a structure such as a flexible pipe as shown in WO2009/068907 can reduce a peak strain seen by the optical fibres to a certain extent they are inherently limited in that they can not be used to measure along a single axis, deployed onto a circumferentially discontinuous structure or provide accurate data if the period of the helix is a poor fit with the discrimination length of the optical time domain reflectometer/optical time domain analyser system being used.

Strain limitations based on the Ultimate Tensile Strain (UTS) of fibre optic cables are currently in the region of 1% according to manufacturers recommendations. The use of commercially available optical fibres to measure strains above 1% thus requires a method of reducing the amount of strain that the fibre is subjected to thereby increasing its capability to measure strain levels beyond its UTS limit.

It is an aim of the present invention to at least partly mitigate the above-mentioned problem.

It is an aim of certain embodiments of the present invention to provide a way of demagnifying the strain that an optical fibre is subjected to so that an underlying structure can be strained, and that strain monitored and measured, without failure of any part of the monitoring system.

It is an aim of certain embodiments of the present invention to provide an apparatus and method for monitoring parameters associated with an elongate structure, such as, but not limited to a flexible pipe, turbine blade, aircraft wing, yacht mast or the like.

It is an aim of certain embodiments of the present invention to provide an optical fibre based parameter measuring/monitoring system which provides a good degree of resolution, that is to say providing a high number of data points per unit length of a target structure, in addition to decoupling strains experienced from an underlying structure from the optical fibre monitoring system.

It is an aim of certain embodiments of the present invention to provide a localised, semi-distributed or distributed strain measurement system able to utilise Brillouin scattering and/or Bragg gratings in a fibre optic system.

It is an aim of certain embodiments of the present invention to provide a method and apparatus for monitoring temperature and/or strain and/or some other parameter associated with an underlying structure.

According to a first aspect of the present invention there is provided an apparatus for monitoring at least one parameter associated with an elongate structure, comprising:

at least one elongate support body element arranged along a longitudinal structure axis associated with an elongate target structure; and at least one optic fibre element arranged substantially helically along a longitudinal body element axis associated with the at least one support body element.

According to a second aspect of the present invention there is provided a method of monitoring at least one parameter associated with an elongate structure, comprising the steps of: providing at least one elongate support body element, comprising at least one optic fibre element arranged substantially helically along a longitudinal body element axis associated with the body element, along a longitudinal structure axis associated with an elongate target structure; and via a sensing system, monitoring at least one characteristic associated with the fibre element, said characteristic being indicative of a parameter associated with the elongate structure.

According to a third aspect of the present invention there is provided a method of manufacturing flexible pipe body comprising: providing a fluid retaining layer; providing at least one armour layer; and providing at least one elongate support body element, comprising at least one optic fibre element arranged substantially helically along a longitudinal body element axis associated with the body element, along a longitudinal pipe body axis associated with the pipe body.

According to a fourth aspect of the present invention there is provided an apparatus for monitoring at least one parameter associated with an elongate structure, comprising: at least one optic fibre element arranged substantially helically along a longitudinal body element axis of an elongate support body element, said body element being arranged along a longitudinal structure axis; wherein a length of the fibre element between first and second planes spaced apart along, and perpendicular to, the longitudinal structure axis, is greater than a comparable length of the optic fibre element wound, at a predetermined pitch, between the first and second planes.

Certain embodiments of the present invention provide the advantage that a length of optical fibre which can be provided between chosen points of a target structure is greater than a comparable length which prior art techniques can provide. The extra length relative to the prior art techniques means that if an underlying structure contracts or extends in length by a certain distance there is a proportional contraction/extension in the optical fibre which is less than the contraction/extension experienced with prior known techniques.

Certain embodiments of the present invention provide the advantage that an optical fibre may be wound in a substantially helical fashion around an underlying support layer which is then located along a predetermined length of the structure where a parameter is to be monitored. This enables the fibre optics to be duly located and monitored in an efficient manner.

Embodiments of the present invention will now be described hereinafter, by way of example only, with reference to the accompanying drawings in which:

Figure 1 illustrates a free hanging catenary riser;

Figure 3 illustrates regions of a flexible pipe;

Figure 2 illustrates flexing of a bend stiffener and pipe body;

Figure 4 illustrates an optic fibre winding around an underlying cylindrical body;

Figure 5 illustrates winding an optic fibre;

Figure 6 illustrates winding an optic fibre;

Figure 7 illustrates a support body and fibre optic winding arranged in a linear fashion;

Figure 8 illustrates a support body and fibre optic winding arranged in a helical fashion;

Figure 9 illustrates a rectangular support body and fibre optic winding; and

Figure 10 illustrates a system for monitoring parameters associated with a flexible pipe and carrying out analysis;

Figure 1 illustrates a flexible pipe (10) which includes a length of flexible pipe body (11) terminated at a first end (12) with an end fitting (13) and terminated at a further end (14) with a further end fitting (15). The flexible pipe extends from a seabed region (16) to a surface region (17). A floating platform (18) is used to secure an upper end fitting (15) of the pipe. A bend stiffener (19) is utilised to limit the bending of the flexible pipe as will be appreciated by those skilled in the art.

Figure 1 thus illustrates an example of an elongate structure, in this case a flexible pipe, in which motion induced in the flexible pipe causes stresses and strains and/or temperature fluctuations which from time to time or constantly it is advisable to monitor.

It is to be appreciated that certain embodiments of the present invention are applicable to a broad range of structures where one or more parameters associated with those structures are to be monitored. For example, instead of a flexible pipe, embodiments of the present invention can monitor parts of bridges, road surfaces and/or land regions and/or lamp-posts and/or wind turbine blades and/or yacht masts and/or suspended power cables or the like.

Turning again to the flexible pipe illustrated in Figure 1, a parameter which might be determined is fatigue damage to the pipe structure under the bend stiffener as in such a system this region is predicted to be the area where maximum fatigue damage to tensile layers of the flexible pipe will occur. Certain embodiments of the present invention provide a system which will collect data which will be stored in a database and this can be utilised in real time or at a later point in time to understand the fatigue and movement behaviour of the pipe in service. This can be compared to pre-stored predicted values which will allow revised life predictions to be made on the pipe system and/or early prediction of problems or failure.

The system can be utilised to calibrate system models to more accurately predict the real world system behaviour which will allow less conservatism in system design based on revised models.

A parameter which it is advantageous to monitor in such a system is the region of pipe in high tension low curvature systems is predicted to be inside the bend stiffener at the top of the riser. This area is subjected to high tension and the highest topside curvature which combines to produce the area of maximum fatigue damage to the tensile layers.

Since the curvature of the pipe decays rapidly over about 5 to 6 meters from the bend stiffener tip the maximum curvature will be inferred by measuring the curvature in that region and curve fitting the data to a predictive model which will provide an estimate of the induced maximum curvature. A modelling system such as Orcaflex™ and/or locally generated models can predict the curvature for pipe systems designed and can produce similar models for in service systems. Figure 2 illustrates how analysis can provide a plot which shows the curvature predictions for a production system (in the example shown a riser). The x axis is the meterage of the pipe around the bend stiffener so Figure 2 illustrates from 6 metre above the flange of the bend stiffener (15) to 11 metres below the bend stiffener flange (11 metres). The central horizontal line (21) represents the area where the bend stiffener covers the pipe. In this system the peak curvature is predicted at around 0.9 to 1 metres and this equates to a minimum bending radius of the pipe of around 8 metres however in a lower region (20) the measured radius is only between 50 metres at the 5 metre end and 1,000 metres at the 9 metre end. This what the curvature measurement system will measure.

The shape of the curve is predicted to be similar to the system being monitored so that although each riser system has a different shape decay curve that curve is similar for the different wave patterns the riser will be subjected to. Hence, if the curve shape is known and the curvature is measured using an optical fibre system the maximum curvature is able to be predicted by using curve fitting algorithms. Combining curvature data and

tension allows the fatigue damage at the point of maximum damage to be calculated. With the fatigue data it is possible to predict the remaining life of the system. Actual damage versus predicted damage. Changes to the pipe behaviour indicating a possible excursion which may be damaging to the riser system.

The monitoring system may utilise different types of sensor system. One, two or more different types of sensor system can be utilised to provide data points for further analysis. For example, tension in the system may be determined using strain gauges or load cells or the like which detect the gross tension of the flexible pipe topside or by using a stress measurement method such as MAPs which uses magnetic sensors to determine the stress induced in the flexible pipe. Another type of sensor which might be used is an angle of inclination sensor. This provides useful information which can be an indicator of vessel or bend stiffener inclination.

There are one or more methods of determining strain using optical fibres. Alternatively or additionally, optical fibres can be utilised to determine temperature at positions along the structure. This would be an example of distributed system. Embodiments of the present invention are not restricted to such distributed systems. An optic fibre is utilised as a distributed strain gauge (or temperature gauge) providing an average strain value for a predetermined (for example, 1 metre) length of fibre as a data point. Then the one metre average is moved approximately 400 mm and another data point is given. Therefore a strain over 1m of fibre is provided each 400 mm of the fibre length. An advantage of this system is the use of relatively inexpensive optical fibre can be utilised and a number of data points produced is high.

Figure 3 illustrates other locations where monitoring of parameters associated with a flexible pipe can be utilised. Such locations include sub-sea arches (30) and/or touchdown points (31) where the range of strain induced in the flexible pipe may be as high as plus or minus 7% or greater and long lengths of hundreds of metres may be monitored. These measurements will be required for pipe systems where the predicted high fatigue damage locations are not necessarily the topside area but are other locations. Other regions including, optionally the whole length, can be monitored.

Brillouin scattering and/or Bragg gratings or other sensing techniques may be used with the optic fibres according to certain embodiments of the present invention. Bragg grating systems use a fibre which has been written with a discreet grid in regions which act as strain gauges (or temperature gauges). These systems work at high frequencies and are very accurate as they pick up a strain or temperature along a very small region (5mm or smaller). The Bragg gratings can be multiplexed on a single fibre. That is to say, an

interrogator can see through one Bragg to a more distant one as long as the reflected frequencies do not overlap.

Figure 4 illustrates how one or more optic fibre (40) is wrapped around and bonded to a cylindrical support body (41) in a helical formation. Straining the cylindrical support body (41) will consequently strain the optic fibre. As an alternative to bonding the optic fibre (41) directly to the cylinder a helical groove (50) may be cut into the cylinder to take the fibre as shown in Figure 5. Figure 6 illustrates a helical optic fibre positioned in the internal bore of a tube and held in place by an adhesive such as epoxy or the like.

As indicated in Figure 4, a cross-section of the support body (41) is substantially circular in cross-section having a diameter d. The fibre Length between spaced apart planes AB which are axially spaced apart with respect to a longitudinal axis X associated with the support member as separated by a distance P which in Figure 4 illustrates the pitch of the winding of the optic fibre (40). It will be appreciated that the length of the fibre is given by:

$$L = \sqrt{(\pi \, \mathrm{d})^2 + P^2} \qquad \text{..... Equation 1}$$

This is shown in Figure 4.

Figure 7 illustrates how the optic fibre winding and support body (41) illustrated in Figures 4 to 6 can be arranged in a linear arrangement along a longitudinal axis Y associated with a target structure which is to be monitored. As illustrated in Figure 7, the fibre length from two planes A and B spaced apart longitudinally along the axis Y of the target structure is given by:

$$L = \frac{H}{P}\sqrt{(\pi \, \mathrm{d})^2 + P^2} \qquad \text{.....Equation 2}$$

Here, H is the distance where strain is measured.

The optic fibre bonded directly along the length of the cylinder (41) experiences the same strain as the cylinder. By increasing the length of the fibre by wrapping it around the support body the overall strain that the fibre is subjected to is reduced. Increasing the amount of wraps on a given length of section results in greater strain de-amplification. This method allows a cylinder with bonded optic fibre to be subjected to a strain around a radius R which is beyond the breaking strain of the fibre. Aptly, the support body is of small enough diameter to allow a minimum of one turn to satisfy a discrimination length of a sensing system utilised.

Aptly, the helix is wrapped relatively tightly and in close proximity to the underlying body to achieve a high de-amplification co-efficient.

Aptly, the support body remains elastic over a large strain range.

As the angles needed to achieve high strain rates are large in relation to the strain axis (for example, 45° to the strain axis theoretically only results in a geometric de-amplification co-efficient of 1.4:1, the actual value is possibly slightly higher than this due to the narrowing of the support due to the Poisson effect which is lower than the de-amplification co-efficient that is needed to measure large strains in elastomeric or highly bent systems) the support body is large enough not to bring about any damage to the fibre or exceed the critical angle. The length of fibre and angle of fibre to strain direction may optionally be appropriately matched to get the optimum measuring requirements such as, but not limited to, sensitivity, resolution and de-amplification.

Aptly, a minimum bend radius of the optic fibre is not exceeded. Aptly, a radius of curvature of the optic fibre wound about the support body is not so tight that the fibre boundary exceeds a critical angle associated with the optic fibre.

Figure 8 illustrates an alternative way in which the optic fibre and support structure may be arranged with respect to the underlying target structure. As illustrated in Figure 8 rather than lay the support body in a linear fashion along the longitudinal axis of the target structure, the support body and helically wound optic fibre may themselves be helically wound around the target structure. This further enhances the introduction of a greater fibre length for a given distance between planes along the longitudinal axis of the target structure.

For example, as shown in Figure 8 the fibre length from planes A and B separated by a pitch distance H is given by:

$$L = \frac{\sqrt{(\pi D)^2 + H^2}}{P}\sqrt{(\pi \mathrm{d})^2 + P^2} \qquad \ldots\ldots\ldots \text{Equation 3}$$

Figure 9 illustrates an alternative embodiment of the present invention in which an optic fibre (90) is helically wound around an underlying support body (91) which has a substantially rectangular cross-section with rounded end regions (92). A length of the support body (91) is b and a width of the support body is d. A fibre length between adjacent planes spaced apart along a longitudinal axis of the support body and substantially perpendicular thereto is P. This is a pitch of winding of the optic fibre. The fibre length L is given by:

$$L = \sqrt{(\pi \mathrm{d} + 2(b-d))^2 + P^2} \qquad \ldots\ldots\ldots \text{Equation 4}$$

The optic fibre (90) and the rectangular shaped rod (91) of Figure 9 may be utilised as described in Figures 7 or 8 noted above. That is to say, as per Figure 7, the optic fibre and

rectangular support body may be provided linearly along a longitudinal axis associated with the target structure. Thus, at least one optic fibre element is arranged substantially helically along a longitudinal body element axis associated with at least one support body element with that support body element itself being arranged along a longitudinal structure axis associated with an elongate target structure. Alternatively, as shown in Figure 8, the optic fibre and rectangular support body may itself be wrapped helically along a longitudinal axis of a target structure. Thus, at least one optic fibre element is arranged substantially helically along a longitudinal body element axis associated with at least one support body element and that support body element is itself arranged along a longitudinal structure axis associated with an elongate target structure.

When the optic fibre and rectangular support body are wrapped in a linear fashion as shown in Figure 7 the fibre length from A to B (L) is:

$$L = \frac{H}{P}\sqrt{(\pi \mathrm{d} + 2(b-d))^2 + P^2} \qquad \text{..... Equation 5}$$

When the optic fibre and rectangular support body are arranged as illustrated in Figure 8 the fibre length from A and B which is L is:

$$L = \frac{\sqrt{(\pi D)^2 + H^2}}{P}\sqrt{(\pi \mathrm{d} + 2(b-d))^2 + P^2} \qquad \text{..... Equation 6}$$

It will be appreciated that one, two or more optic fibre and support body arrangements may be themselves arranged along a longitudinal axis of a structure in which a parameter is to be sensed. Each optic fibre is repeatedly or continuously bonded to the support body about which it is helically wound.

The following examples have been chosen to achieve measurable strain sensitivity using standard measuring equipment.

Examples, assume **d = 5 mm , b = 50 mm and H = 500 mm**

Then for Figure 4 - L = 500.24 mm (0.05% increase in length L)

for Figure 9 - L = 511.05 mm (**2.2% increase** in length L compared to Case 1)

If **P = 50 mm and** d = 5 mm, b = 50 mm and H = 500 mm

Then for Figure 7 as per Figure 4 - L = 524.09 mm (4.8% increase in length L compared to Figure 4)

for Figure 7 as per Figure 0 **-** L = 1169.36 mm **(134% increase** in length L compared to Figure 4)

If **D = 200 mm and** P = 50 mm, d = 5 mm, b = 50 mm and H = 500 mm

Then for Figure 8 as per Figure 4 - L = 841.67 mm (68.2% increase in length L compared to Figure 4)

for Figure 8 as per Figure 9 - L = 1877.9 mm **(276% increase** in length L compared to Figure 4)

Where the % increase in L is proportional to the strain demagnification for the specific method/winding technique used.

If a parameter being monitored is temperature it is possible to pack more and more fibres per unit length of the support body by winding windings of the optic fibre more tightly. It will be appreciated that when this is done the angle the winding makes with respect to the axis of the support body approaches 90°. This maximises a strain demagnification effect and increases resolution of a system. Other parameters may be similarly dealt with however when strain is monitored a trade off can be made depending upon the circumstances (whether strain demagnification, resolution and/or measuring sensitivity is most important for a particular use) to select the pitch of winding on the support body and thus the number of windings per unit length versus the angle the optic fibre makes with respect to the strain direction. Having a helix angle close to normal to a strain direction will demagnify a strain on a fibre close to zero, will increase resolution, but will reduce sensitivity. Here resolution is an effective distance between measurement points. Sensitivity is related to an accuracy of measurements made at those points.

According to certain embodiments of the present invention, in which the elongate target structure is a flexible pipe, the flexible pipe may have one or more armour layers. Such armour layers are typically formed during a manufacturing phase by wrapping armour wire windings helically around an underlying layer. It will appreciated that embodiments of the present invention can replace one or more of the armour wire windings with an optic fibre and support body having a cross-section compatible with or matching a cross-section of the armour wire. In such a circumstance, the pitch at which the optic fibre and support body is wound is determined by a pitch selected during the design and manufacture of the flexible pipe.

The rectangular-shaped rod with radius corners illustrated in Figure 9 may be manufactured from a material that can sustain elastic behaviour up to the maximum strain levels that are expected to be measured in service. The rod material could, for example, be metallic, polymeric or composite or the like. A groove is provided to lay and fix the optical fibre into the rod. The fibre is bonded using readily available adhesives suitable for the surface of the rod/structure assembly. The path of the groove is designed so that the

axial traverse of the group along the length of the rod is the same over the entire length of the groove, giving a fixed orientation of the groove relative to the axis of the rod. The strain monitoring rod can be temporarily attached, permanently bonded or directly incorporated to the structure where strain/displacement is to be monitored.

When the rod is strained due to the application of loads to the structure, the strain on the optical fibre that is at an angle to the axis of the rod will be lower and proportional to the strain in the rod. The relationship of the strain on the fibre to the strain on the rod is given by the following equation:

$$\frac{\varepsilon_{Fibre}}{\varepsilon_{Rod}} = \left(\frac{1-\nu}{2}\right) + \left(\frac{1+\nu}{2}\right) Cos2\theta \text{ where } Tan\theta = \frac{2(b-d)+\pi d}{P} \text{ and } 2R = d$$

For example, if the thickness of the rod b is 25 mm, the thickness of the rod d is 5 mm and a pitch P is a 60 mm in a steel rod (Poisson's ratio V – 0.3) then strain attenuation (de-magnification) is:

$$\frac{\varepsilon_{Fibre}}{\varepsilon_{Rod}} \approx 0.4 \ (40\%) \qquad \ldots\ldots\ldots \text{Equation 8}$$

The minimum value of R which is a radius of curvature at the radius ends of the rectangular rod depends on a maximum strain that the fibre can sustain.

The simplest form of this development is a grooved cylindrical rod (L= 0). However, an achievable amount of de-magnification is low unless the rod diameter is large as the optic fibre can only work as a light conduit up to a certain bend radius and as the bend radius decreases, the light is gradually lost through walls of the fibre. Use of a rectangular rod has an advantage that length of fibre can be increased without increasing the diameter of the rod.

The shape of the rod has the benefit that the strain measurement is insensitive to the bending of the rod as the tensile and compressive strains cancel out when used with a distributed strain sensing system. Cancelling the bending effect applies equally to both circular and elongated cross sections of rod. Aptly the averaging distance of the strain measurement equals the length L of the fibre over one pitch of spiral. In such circumstances only the axial strength of the rod is measured. Aptly, the system can be used with a Bragg grating-based discrete sensing system to reduce gross strain on the fibre.

The rod may aptly be manufactured by various methods such as machining, extrusion then machining or by use of a number of overlapping rollers with the impression of the groove used to form the groove on a pre-formed rod. Alternatively, the rod may be manufactured using rapid prototyping techniques such as laser centring or 3D printing.

Figure 10 illustrates a configuration of hardware/software according to embodiments of the present invention. One or more sensors are monitored either by a single monitoring unit with multiple inputs or a number of monitoring units with a common timebase. This data is transferred to a database where the data will be stored in a manner which allows easy interrogation. Due to data quantity it is preferable that a short-term detailed data set will be kept for a period of, for example, six months which will include all data recorded then a further database will be used to store longer term trend data which can be created by compressing the short-term data. The short-term data is used in case of accident or failure.

Throughout the description and claims of this specification, the words “comprise” and “contain” and variations of them mean “including but not limited to”, and they are not intended to (and do not) exclude other moieties, additives, components, integers or steps. Throughout the description and claims of this specification, the singular encompasses the plural unless the context otherwise requires. In particular, where the indefinite article is used, the specification is to be understood as contemplating plurality as well as singularity, unless the context requires otherwise.

Features, integers, characteristics, compounds, chemical moieties or groups described in conjunction with a particular aspect, embodiment or example of the invention are to be understood to be applicable to any other aspect, embodiment or example described herein unless incompatible therewith. All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive. The invention is not restricted to the details of any foregoing embodiments. The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

The reader's attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

CLAIMS

1. Apparatus for monitoring at least one parameter associated with an elongate structure, comprising:

at least one elongate support body element arranged along a longitudinal structure axis associated with an elongate target structure; and

at least one optic fibre element arranged substantially helically along a longitudinal body element axis associated with the at least one support body element.

2. The apparatus as claimed in claim 1 wherein the support body element is arranged substantially straight along said a longitudinal structure axis.

3. The apparatus as claimed in claim 1 wherein the support body element is arranged substantially helically along said longitudinal structure axis.

4. The apparatus as claimed in any one of claims 1 to 3, further comprising:

each optic fibre element is repeatedly or continuously bonded to said at least one body element.

5. The apparatus as claimed in any one of claims 1 to 4, further comprising:

each optic fibre element is arranged about an external surface of the at least one body element.

6. The apparatus as claimed in any one of claims 1 to 4, further comprising:

each optic fibre element is arranged in a grooved region extending substantially helically about an external surface of the at least one body element.

7. The apparatus as claimed in any preceding claim, further comprising:

the at least one body element and the at least one fibre element are arranged to allow the target structure to be subjected to a strain around a Radius R said a strain exceeding a normal breaking strain associated with the fibre element.

8. The apparatus as claimed in any preceding claim, further comprising:

the at least one body element has a diameter small enough to allow a minimum of one turn of the fibre element to satisfy a discrimination length of a sensing system connected to the fibre element.

9. The apparatus as claimed in any preceding claim, further comprising:

the fibre element is arranged closely proximate to the body element.

10. The apparatus as claimed in any preceding claim wherein the body element is elastomeric.

11. The apparatus as claimed in any preceding claim, further comprising:

the at least one fibre element is arranged whereby the minimum bend radius of the fibre is not exceeded and a fibre boundary does not exceed a critical angle of the fibre element.

12. The apparatus as claimed in any preceding claim, further comprising:

the substantially helical arrangement of the at least one fibre element follows a substantially identical axial traverse along a whole length of the body element.

13. The apparatus as claimed in any preceding claim, further comprising:

the at least one body element comprises a rod member having a constant cross section, a shape of the cross section being a rectangle with rounded corners or an oval or a circle or an ellipse.

14. The apparatus as claimed in claim 13 wherein the rod member is a metallic or polymeric or composite material.

15. The apparatus as claimed in claim 13 or 14, further comprising:

the rod member is temporarily attached or permanently bonded or directly incorporated to the target structure.

16. The apparatus as claimed in any preceding claim, further comprising:

a sensing system connectable to at least one end of the fibre element.

17. The apparatus as claimed in any preceding claim wherein the at least one parameter comprises strain or temperature.

18. The apparatus as claimed in any preceding claim wherein the target structure comprises a portion of one of a bridge or road surface or lamp post or wind turbine blade or yacht mast or suspended power cable or aircraft body piece.

19. The apparatus as claimed in any one of claims 1 to 15, further comprising:

the elongate target structure comprises flexible pipe body comprising a fluid retaining layer and at least one armour layer.

20. The apparatus as claimed in claim 19, further comprising:

the at least one body element comprises a substrate member wound at a pitch matching a pitch of winding in the armour layer, the fibre element being arranged substantially helically around an outer surface of the substrate member.

21. The apparatus as claimed in claim 19, further comprising:

the at least one body element comprises a hollow body member wound at a pitch matching a pitch of winding in the armour layer, the fibre element being arranged substantially helically around an inner surface of the hollow body member.

22. The apparatus as claimed in any one of claims 19 to 21, further comprising:

a first and second end fitting terminating a respective first and second end of the flexible pipe body, the at least one fibre element extending at least between the first and second end fittings or between a portion of the pipe body between the first and second end

fittings or between an intermediate point along the flexible pipe body and a one of the first and second end fittings.

23. The apparatus as claimed in any one of claims 19 to 22, further comprising:

the flexible pipe body comprises pipe body of a flexible pipe comprising a riser or flowline or jumper.

24. A method of monitoring at least one parameter associated with an elongate structure, comprising the steps of:

providing at least one elongate support body element, comprising at least one optic fibre element arranged substantially helically along a longitudinal body element axis associated with the body element, along a longitudinal structure axis associated with an elongate target structure; and

via a sensing system, monitoring at least one characteristic associated with the fibre element, said characteristic being indicative of a parameter associated with the elongate structure.

25. The method as claimed in claim 24, further comprising:

providing the body element comprises laying the body element substantially straight along the structure axis.

26. The method as claimed in claim 24, further comprising:

providing the body element comprises helically winding the body element along the structure axis.

27. A method of manufacturing flexible pipe body comprising:

providing a fluid retaining layer;

providing at least one armour layer; and

providing at least one elongate support body element, comprising at least one optic fibre element arranged substantially helically along a longitudinal body element axis

associated with the body element, along a longitudinal pipe body axis associated with the pipe body.

28. The method as claimed in claim 27, further comprising:

providing the support body element by helically winding the support body element as a winding of the armour layer.

29. Apparatus for monitoring at least one parameter associated with an elongate structure, comprising:

at least one optic fibre element arranged substantially helically along a longitudinal body element axis of an elongate support body element, said body element being arranged along a longitudinal structure axis; wherein

a length of the fibre element between first and second planes spaced apart along, and perpendicular to, the longitudinal structure axis, is greater than a comparable length of the optic fibre element wound, at a predetermined pitch, between the first and second planes.

30. The apparatus as claimed in claim 29 wherein said predetermined pitch comprises a helical pitch of the fibre element arranged along the body element.

31. The apparatus as claimed in claim 29 wherein said predetermined pitch comprises a largest possible pitch small enough to allow a minimum of one turn of the fibre element to satisfy a discrimination length of a sensing system connected to the fibre element.

32. The apparatus as claimed in claim 29 wherein said predetermined pitch is a pitch which maintains a bend radius of the fibre element equal to or below a minimum bend radius and a fibre boundary equal to or below a critical angle of the fibre element.

33. The apparatus as claimed in claim 29 wherein said elongate structure comprises a flexible pipe comprising an armour layer comprising helically wound armour wire windings, said predetermined pitch comprising a pitch of winding of said wire windings.

34. Apparatus constructed and arranged substantially as hereinbefore described with reference to the accompanying drawings.

35. A method substantially as hereinbefore described with reference to the accompanying drawings.

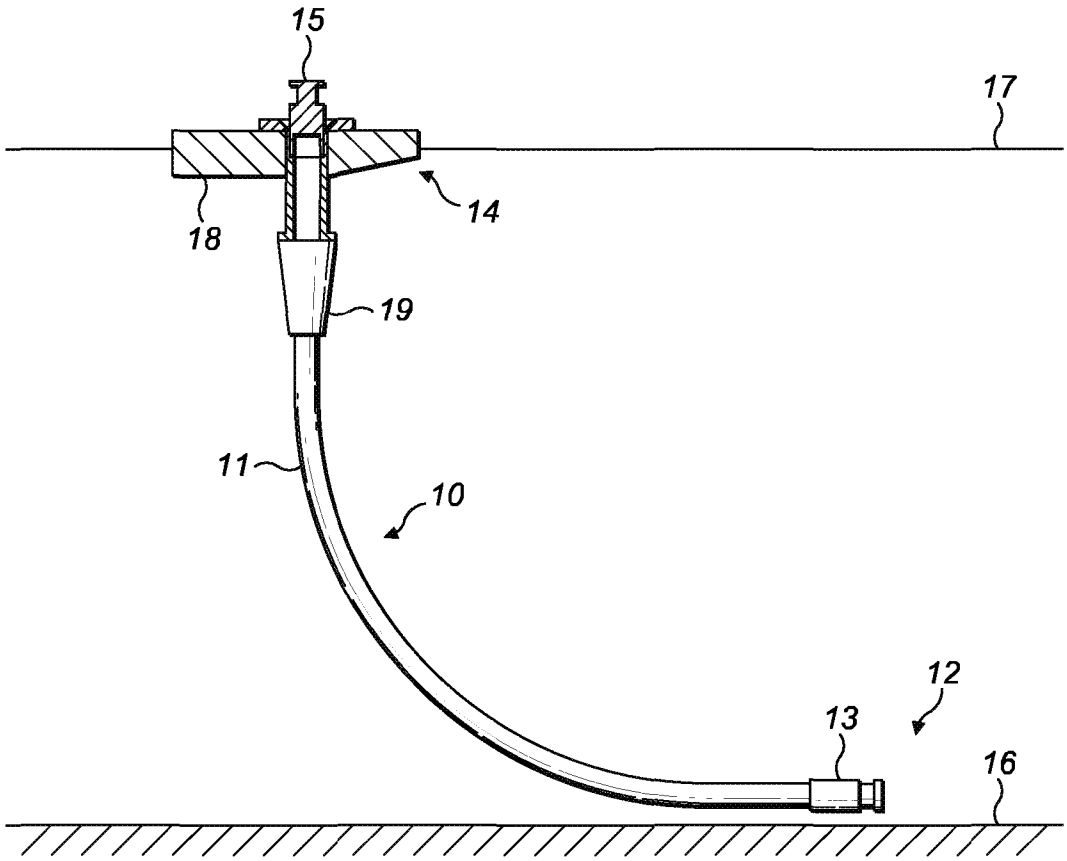

15
17
14
18
19
11
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12
13
16

FIG. 1

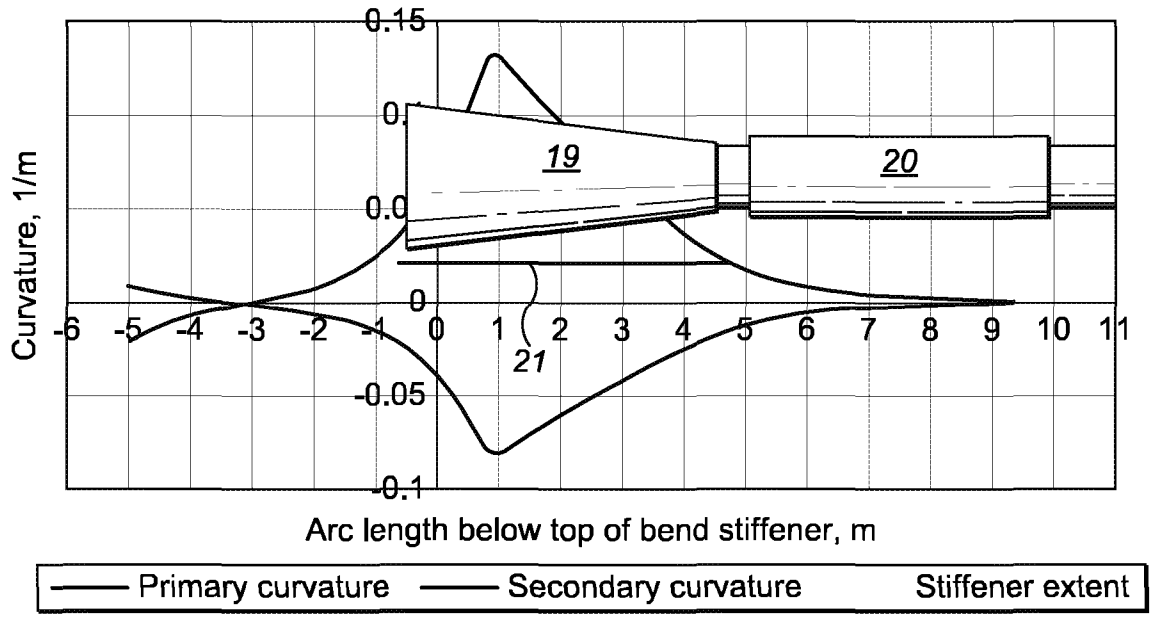

0.15
0.1
0.0
0
-0.05
-0.1
Curvature, 1/m
19
20
21
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11
Arc length below top of bend stiffener, m
Primary curvature
Secondary curvature
Stiffener extent

FIG. 2

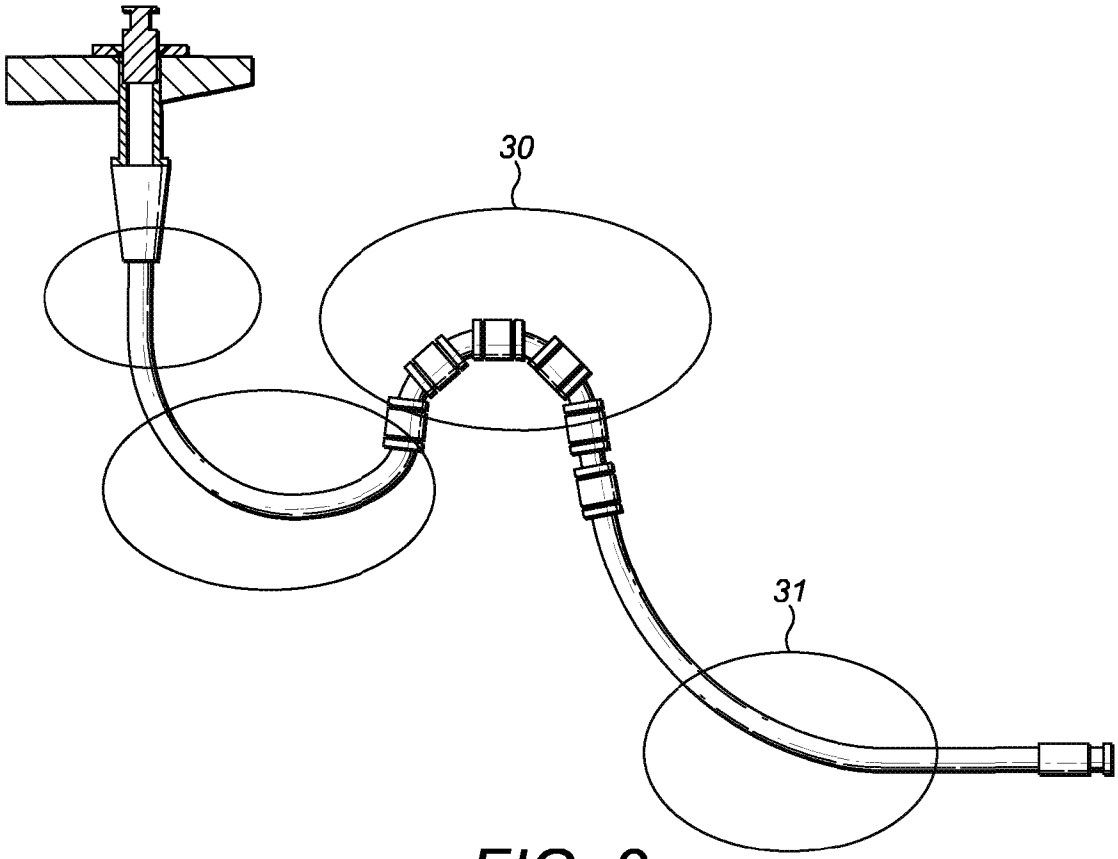

30
31

FIG. 3

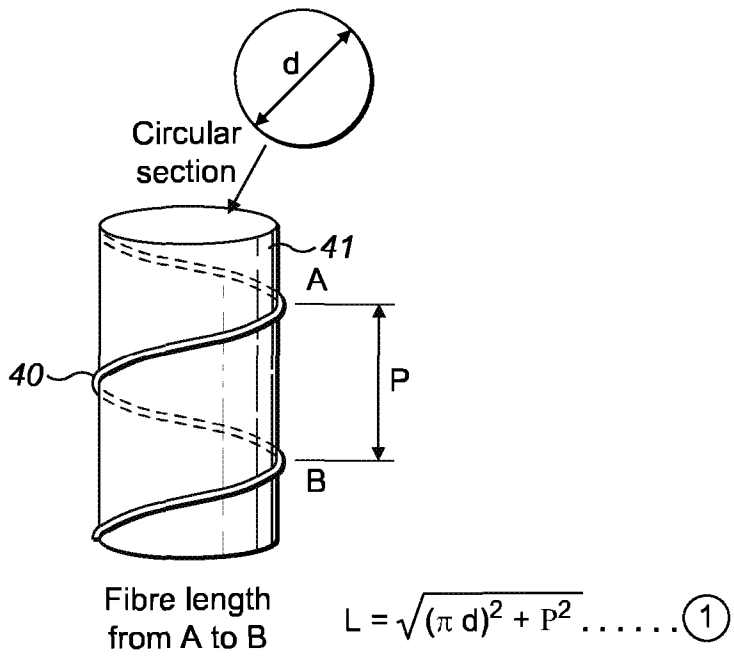

d
Circular section
41
A
40
P
B
Fibre length from A to B
$L = \sqrt{(\pi d)^2 + P^2}$ . . . . . (1)

FIG. 4

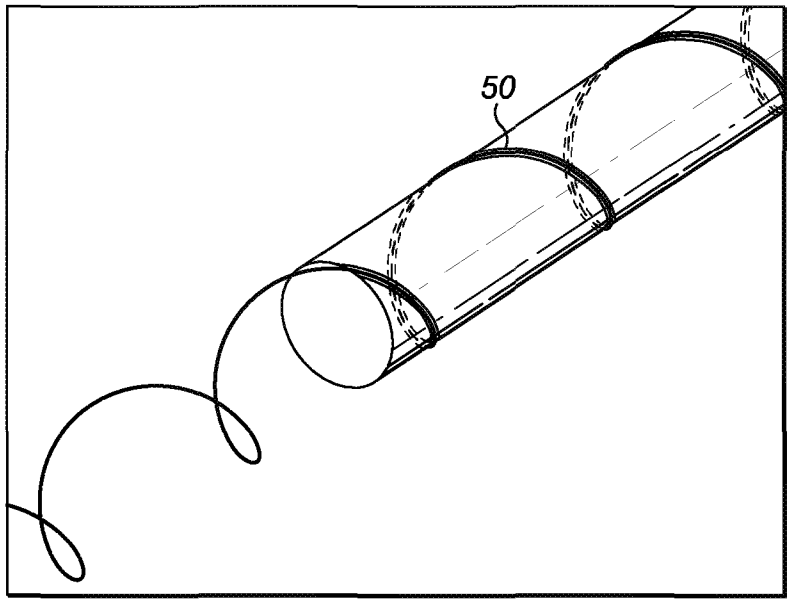


FIG. 5

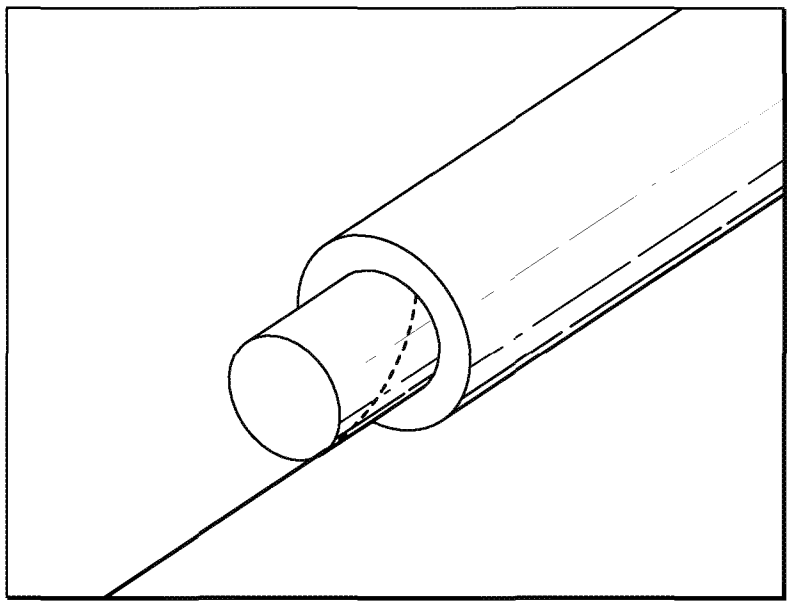
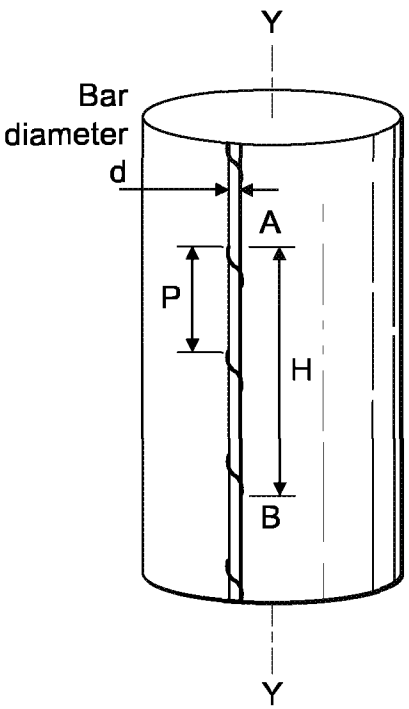


FIG. 6



P is the minimum resolution for the measurement

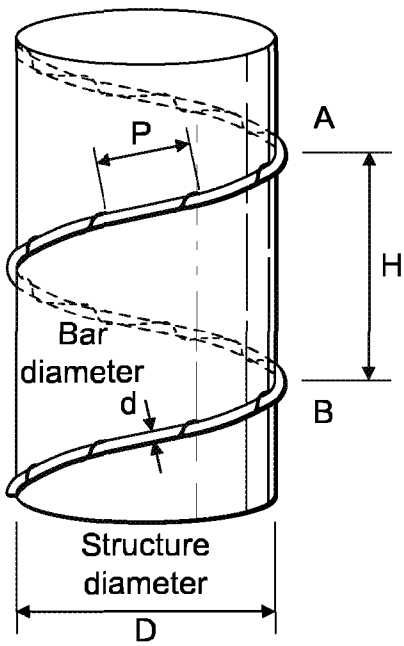
Case 3a - Fibre wrapped bar as in Case 1

Fibre length from A to B $L = \frac{H}{P}\sqrt{(\pi d)^2 + P^2}$ ..... (2)

Case 3b - Fibre wrapped bar as in Case 2

Fibre length from A to B $L = \frac{H}{P}\sqrt{(\pi d) + 2(b - d))^2 + P^2}$ ..... (5)

FIG. 7



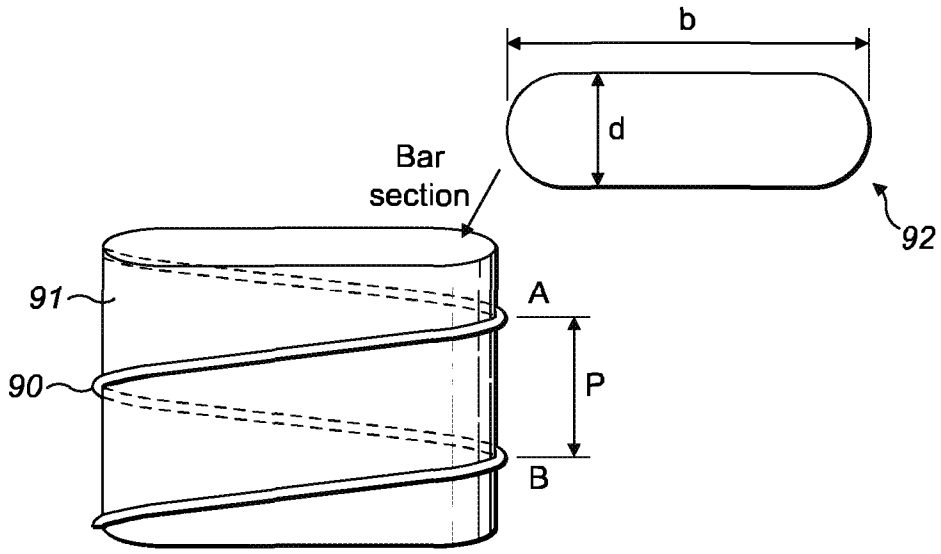
Case 4a - Fibre wrapped bar as in Case 1

Fibre length from A to B $L = \frac{\sqrt{(\pi D)^2 + H^2}}{P}\sqrt{(\pi d)^2 + P^2}$ ..... (3)

Case 4b - Fibre wrapped bar as in Case 2

Fibre length from A to B $L = \frac{\sqrt{(\pi D)^2 + H^2}}{P}\sqrt{(\pi d) + 2(b - d))^2 + P^2}$ ..... (6)

FIG. 8



Fibre length from A to B $L = \sqrt{(\pi d + 2(b - d))^2 + P^2}$ ..... (4)

FIG. 9

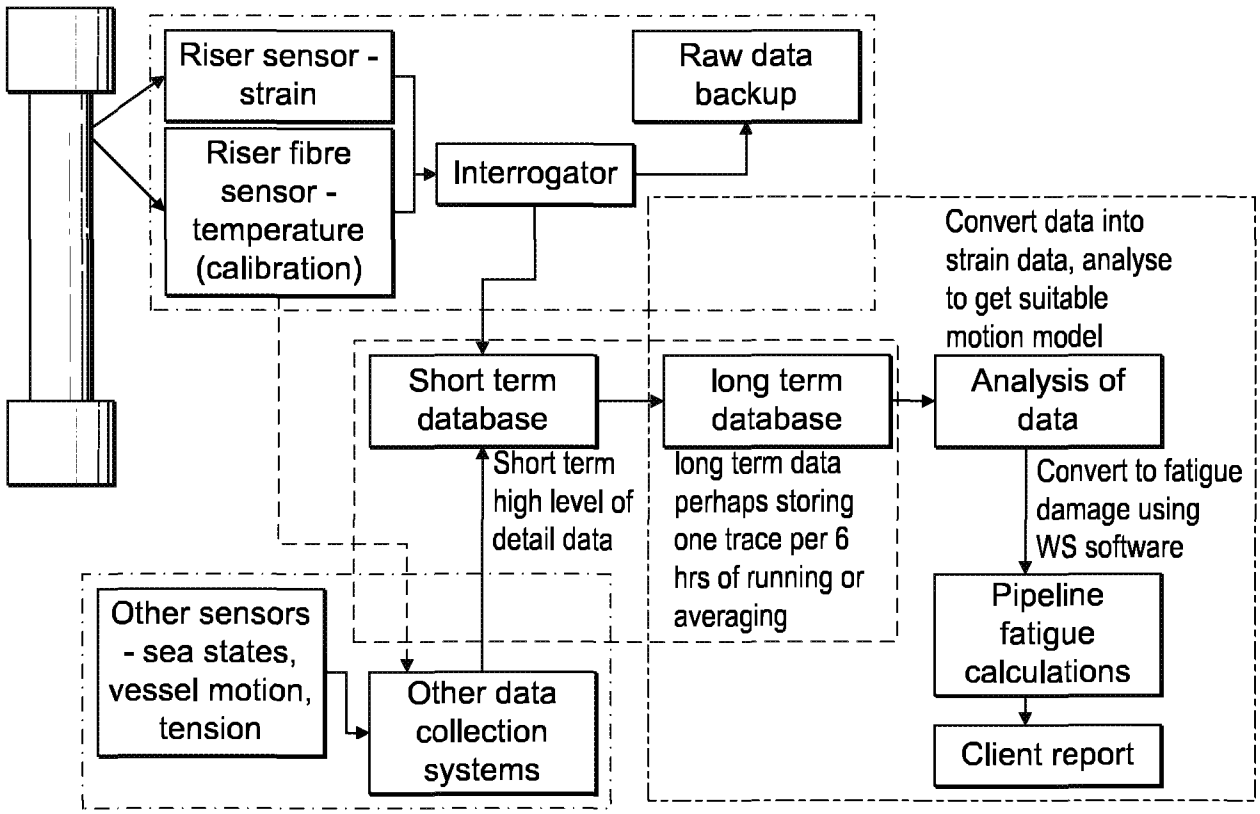


FIG. 10