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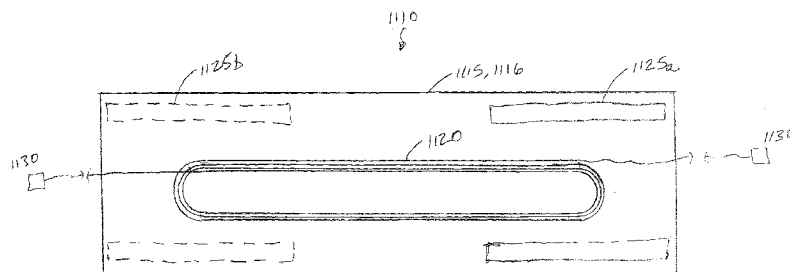


FIG. 13

(57) Abstract: An apparatus to detect a pressure signal in a fluid flowing in a conduit comprises a flexible band sized to fit at least partially around the conduit. An optical fiber is flexibly adhered to the flexible band. At least one fastener is attached to the flexible band to fasten the flexible band at least partially around the conduit. A method for detecting a pressure signal in a conduit comprises adhering an optical fiber to a flexible band. At least one fastener is attached to the band. The band is fastened around the conduit such that a strain induced in the conduit by the pressure signal is transmitted to the optical fiber.

APPARATUS AND METHOD FOR DETECTING PRESSURE SIGNALS

BACKGROUND OF THE INVENTION

The present disclosure relates generally to the field of telemetry systems for
5 transmitting information through a flowing fluid. More particularly, the disclosure relates to the field of signal detection in such a system.

Sensors may be positioned at the lower end of a well drilling string which, while drilling is in progress, continuously or intermittently monitor predetermined drilling parameters and formation data and transmit the information to a surface detector by some
10 form of telemetry. Such techniques are termed "measurement while drilling" or MWD. MWD may result in a major savings in drilling time and improve the quality of the well compared, for example, to conventional logging techniques. The MWD system may employ a system of telemetry in which the data acquired by the sensors is transmitted to a receiver located on the surface. Fluid signal telemetry is one of the most widely used
15 telemetry systems for MWD applications.

Fluid signal telemetry creates pressure signals in the drilling fluid that is circulated under pressure through the drill string during drilling operations. The information that is acquired by the downhole sensors is transmitted by suitably timing the formation of pressure signals in the fluid stream. The pressure signals are commonly
20 detected by a pressure transducer tapped into a high pressure flow line at the surface. Access to, and penetration of, the high pressure flow line may be restricted due to operational and/or safety issues.

BRIEF DESCRIPTION OF THE DRAWINGS

A better understanding of the present invention can be obtained when the
25 following detailed description of example embodiments are considered in conjunction with the following drawings, in which:

FIG. 1 shows schematic example of a drilling system;

FIG. 2 shows an example block diagram of the acquisition of downhole data and the telemetry of such data to the surface in an example drilling operation;

30 FIGS. 3A-3D show examples of pressure signal transmitter assemblies suitable for use in a fluid telemetry system;

FIG. 4 shows an example embodiment of an optical interferometer system used to detect downhole transmitted pressure signals;

FIG. 5 shows an example of a measurement section fiber adhered to a pliant band;

FIG. 6 is a block diagram showing an example of the processing of a received
5 optical signal;

FIG. 7 is a chart of laboratory test data showing raw interferometer data and integrated interferometer data compared to conventional pressure sensor data for pressure signal detection;

FIG. 8 is shows an example of a modularized version of the optical interferometer
10 system of FIG. 4;

FIG. 9 shows another embodiment of an optical interferometer system used to detect downhole transmitted pressure signals;

FIG. 10 shows an example of a modularized version of the optical interferometer system of FIG. 9;

FIG. 11 shows an embodiment of an optical fiber measurement section wrapped
15 around a conduit;

FIG. 12 shows an exploded view of a portion of one embodiment of an optical fiber measurement section;

FIG. 13 shows one example of an optical fiber measurement section rolled out flat
20 as it appears after fabrication;

FIGS. 14A and 14B show one embodiment of a fixture assembly for fabricating an optical fiber measurement section;

FIG. 15A shows one embodiment of an optical fiber measurement section comprising a flexible metal band;

FIG. 15B shows the installation of the measurement assembly of FIG. 15A on a
25 conduit;

FIG 15C shows an alternative clamp fastener;

FIG. 16 shows another example of an optical fiber measurement section; and

FIG. 17 shows another example of an optical fiber measurement section.

30 While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and will

herein be described in detail. It should be understood, however, that the drawings and detailed description thereto are not intended to limit the invention to the particular form disclosed, but on the contrary, the intention is to cover all modifications, equivalents and alternatives falling within the scope of the present invention as defined by the appended claims.

DETAILED DESCRIPTION

Referring to FIG. 1, a typical drilling installation is illustrated which includes a drilling derrick 10, constructed at the surface 12 of the well, supporting a drill string 14. The drill string 14 extends through a rotary table 16 and into a borehole 18 that is being drilled through earth formations 20. The drill string 14 may include a kelly 22 at its upper end, drill pipe 24 coupled to the kelly 22, and a bottom hole assembly 26 (BHA) coupled to the lower end of the drill pipe 24. The BHA 26 may include drill collars 28, an MWD tool 30, and a drill bit 32 for penetrating through earth formations to create the borehole 18. In operation, the kelly 22, the drill pipe 24 and the BHA 26 may be rotated by the rotary table 16. Alternatively, or in addition to the rotation of the drill pipe 24 by the rotary table 16, the BHA 26 may also be rotated, as will be understood by one skilled in the art, by a downhole motor (not shown). The drill collars add weight to the drill bit 32 and stiffen the BHA 26, thereby enabling the BHA 26 to transmit weight to the drill bit 32 without buckling. The weight applied through the drill collars to the bit 32 permits the drill bit to crush the underground formations.

As shown in FIG. 1, BHA 26 may include an MWD tool 30, which may be part of the drill collar section 28. As the drill bit 32 operates, drilling fluid (commonly referred to as "drilling mud") may be pumped from a mud pit 34 at the surface by pump 15 through standpipe 11 and kelly hose 37, through drill string 14, indicated by arrow 5, to the drill bit 32. The drilling mud is discharged from the drill bit 32 and functions to cool and lubricate the drill bit, and to carry away earth cuttings made by the bit. After flowing through the drill bit 32, the drilling fluid flows back to the surface through the annular area between the drill string 14 and the borehole wall 19, indicated by arrow 6, where it is collected and returned to the mud pit 34 for filtering. The circulating column of drilling mud flowing through the drill string may also function as a medium for transmitting pressure signals 21 carrying information from the MWD tool 30 to the surface. In one

embodiment, a downhole data signaling unit 35 is provided as part of MWD tool 30. Data signaling unit 35 may include a pressure signal transmitter 100 for generating the pressure signals transmitted to the surface.

MWD tool 30 may include sensors 39 and 41, which may be coupled to appropriate data encoding circuitry, such as an encoder 38, which sequentially produces encoded digital data electrical signals representative of the measurements obtained by sensors 39 and 41. While two sensors are shown, one skilled in the art will understand that a smaller or larger number of sensors may be used without departing from the principles of the present invention. The sensors 39 and 41 may be selected to measure downhole parameters including, but not limited to, environmental parameters, directional drilling parameters, and formation evaluation parameters. Such parameters may comprise downhole pressure, downhole temperature, the resistivity or conductivity of the drilling mud and earth formations, the density and porosity of the earth formations, as well as the orientation of the wellbore.

The MWD tool 30 may be located proximate to the bit 32. Data representing sensor measurements of the parameters discussed may be generated and stored in the MWD tool 30. Some or all of the data may be transmitted in the form of pressure signals by data signaling unit 35, through the drilling fluid in drill string 14. A pressure signal travelling in the column of drilling fluid may be detected at the surface by a signal detector unit 36 employing optical fiber loop 230. The detected signal may be decoded in controller 33. The pressure signals may be encoded binary representations of measurement data indicative of the downhole drilling parameters and formation characteristics measured by sensors 39 and 41. Controller 33 may be located proximate the rig floor. Alternatively, controller 33 may be located away from the rig floor. In one embodiment, controller 33 may be incorporated as part of a logging unit.

FIG.2 shows a block diagram of the acquisition of downhole data and the telemetry of such data to the surface in an example drilling operation. Sensors 39 and 41 acquire measurements related to the surrounding formation and/or downhole conditions and transmit them to encoder 38. Encoder 38 may have circuits 202 comprising analog circuits and analog to digital converters (A/D). Encoder 38 may also comprise a processor 204 in data communication with a memory 206. Processor 204 acts according

to programmed instructions to encode the data into digital signals according to a pre-programmed encoding technique. One skilled in the art will appreciate that there are a number of encoding schemes that may be used for downhole telemetry. The chosen telemetry technique may depend upon the type of pressure signal transmitter 100 used.

5 Encoder 38 outputs encoded data 208 to data signaling unit 35. Data signaling unit 35 generates encoded pressure signals 21 that propagate through the drilling fluid in drill string 14 to the surface. Pressure signals 21 are detected at the surface by signal detector 36 and are transmitted to controller 33 for decoding. In one example embodiment, signal detector 36 may be a fiber optic signal detector, described below. Controller 33 may
10 comprise interface circuitry 65 and a processor 66 for decoding pressure signals 21 into data 216. Data 216 may be output to a user interface 218 and/or an information handling system such as logging unit 221. Alternatively, in one embodiment, the controller circuitry and processor may be an integral part of the logging unit 221.

FIGS. 3A-3D show example embodiments of pressure signal transmitter 100.

15 FIG. 3A shows a pressure signal transmitter 100a disposed in data signaling unit 35a. Pressure signal transmitter 100a has drilling fluid 5 flowing therethrough and comprises an actuator 105 that moves a gate 110 back and forth against seat 115 allowing a portion of fluid 5 to intermittently pass through opening 102 thereby generating a negative pressure signal 116 that propagates to the surface through drilling fluid 5.

20 FIG. 3B shows a pressure signal transmitter 100b disposed in data signaling unit 35b. Pressure signal transmitter 100b has drilling fluid 5 flowing therethrough and comprises an actuator 122 that moves a poppet 120 back and forth toward orifice 121 partially obstructing the flow of drilling fluid 5 thereby generating a positive pressure signal 126 that propagates to the surface through drilling fluid 5.

25 FIG. 3C shows a pressure signal transmitter 100c disposed in data signaling unit 35c. Pressure signal transmitter 100c has drilling fluid 5 flowing therethrough and comprises an actuator 132 that continuously rotates a rotor 130 in one direction relative to stator 131. Stator 131 has flow passages 133 allowing fluid 5 to pass therethrough. Rotor 130 has flow passages 134 and the movement of flow passages 134 past flow
30 passages 133 of stator 131 generates a continuous wave pressure signal 136 that propagates to the surface through drilling fluid 5. Modulation of the continuous wave

pressure signal may be used to encode data therein. Modulation schemes may comprise frequency modulation and phase shift modulation.

FIG. 3D shows a pressure signal transmitter 100d disposed in data signaling unit 35d. Pressure signal transmitter 100d has drilling fluid 5 flowing there through and comprises an actuator 142 that rotates a rotor 140 back and forth relative to stator 141. Stator 141 has flow passages 143 allowing fluid 5 to pass therethrough. Rotor 140 has flow passages 144 and the alternating movement of flow passages 144 past the flow passages 143 of stator 141 generates a continuous wave pressure signal 146 that propagates to the surface through drilling fluid 5. Modulation of the continuous wave pressure signal may be used to encode data therein. Modulation schemes may comprise frequency modulation and phase shift modulation.

FIG. 4 shows an example of signal detector 36 comprising an optical interferometer 200 for detecting pressure signals in conduit 211. Interferometer 200 comprises a light source 202, an optical fiber loop 230, an optical coupler/splitter 215, and an optical detector 210. It is noted that optical coupler/splitter as used herein encompasses integrated coupler splitters and individual couplers and splitters. Light source 202 may be a laser diode, a laser, or a light emitting diode that emits light into optical coupler/splitter 215 where the light is split into two beams 231 and 232. Beam 231 travels clockwise (CW) through loop 230, and beam 232 travels counter-clockwise (CCW) through loop 230.

Loop 230 has a length, L , and comprises measurement section 220 and delay section 225. In one embodiment, measurement section 220 may be 2-10 meters in length. In this example, measurement section 220 is wrapped at least partially around conduit 211, which may be standpipe 11 of FIG. 1. Alternatively, measurement section 220 may be wrapped around any section of flow conduit that has pressure signals travelling therein. The length of measurement section 220 is designated by X in FIG. 4, and represents the length of fiber that reacts to hoop strains in standpipe 11 caused by the pressure signals therein. The optical fibers of measurement section 220 may be physically adhered to conduit 211. Alternatively, see FIG. 5, measurement section 220 may comprise a length, X , of optical fiber 302 adhered in a folded pattern to a pliant, also called flexible, band 300 that is attachable to a conduit. In one embodiment, pliant band

300 may be a biaxially-oriented polyethylene terephthalate material, for example a Mylar[®] material manufactured by E.I. Dupont de Nemours & Co. Pliant band 300 may be adhesively attached, for example, to standpipe 11 of FIG. 1 using any suitable adhesive, for example an epoxy material or a cyanoacrylate material.

Delay section 225 may be on the order of 500-3000 meters in length. The small diameter of optical fibers contemplated (on the order of 250 μ m) allows such a length to be wound on a relatively small spool. As shown in FIG. 4, delay section 225 comprises a length identified as L-X. It will be seen that L is a factor in the sensitivity of the sensor.

Counter-propagating beams 231, 232 traverse loop 230 and recombine through coupler/splitter 215, and are detected by photo-detector 210. Under uniform (constant in time) conditions, beams 231, 232 will recombine in phase at the detector 210 because they have both traveled equal distances around loop 230. Consider counter-propagating beams 231, 232 and a time varying pressure P(t) in standpipe 11. Beams 231, 232 will be in phase after they have traveled the distance X in their two paths, and they will be in phase after they have continued through the distance L-X as well. Now, let the pressure within the pipe be changing at a rate of dP/dt during the time Δt while beams 231, 232 travel the distance L-X, then

$$\Delta t = (L - X)n / c ,$$

where c is the speed of light, and n is the refractive index of the optical fiber.

During this time interval, the pressure within the pipe changes by an amount ΔP , which acts to radially expand standpipe 11. This expansion results in a change ΔX in the length, X, of the measurement section 220 of optical fiber 230 wrapped around conduit 211.

Although at the end of the interval Δt the two beams are in phase, they will go out of phase for the last portion of the circuit before they recombine, because the length of measurement section 220 has changed during the previous interval Δt . For the final leg of the trip around the loop, the counter-clockwise beam 232 will travel a distance that is different by an amount ΔX from the clockwise rotating beam 231. When the beams combine at detector 210, they will be out of phase by a phase difference, $\Delta\phi$, where

$$\Delta\phi = 2\pi(\Delta X) / n\lambda ,$$

where λ is the wavelength of the light emitted by source 202. As beams 231, 232 are combined, it can be shown that a factor in the signal will be $\cos(\Delta\phi/2)$. Thus, counter propagating beams 231, 232 will be out of phase when $\Delta X = \lambda$.

The change of the pressure in the pipe during the interval Δt is given by

$$\Delta P = \left(\frac{dP}{dt} \right) \Delta t = \left(\frac{dP}{dt} \right) (L - X) \left(\frac{n}{c} \right).$$

Let K be the sensitivity of the pipe to internal pressure; that is, the change in circumference of the pipe ΔC due to a change in pressure ΔP given by,

$$\Delta C = K(\Delta P)$$

K can be computed from dimensions and material properties of the pipe materials. For example, for a thin-walled pipe, where $D_{\text{pipe}} > 10 \times$ pipe thickness, t , it can be shown that

$$K = \frac{\pi D_{\text{pipe}}^2}{2Et}$$

where E is the modulus of elasticity of the pipe material.

For a thick walled pipe, where $D_{\text{pipe}} \leq 10 \times$ pipe thickness, t , it can be shown that

$$K = \frac{2\pi D_o D_i^2}{E(D_o^2 - D_i^2)}$$

where D_o and D_i are the outer and inner pipe diameters, respectively.

If N_{coil} is the number of turns of fiber around the pipe, then

$$\Delta X = N(\Delta C) = N_{\text{coil}} K \left(\frac{dP}{dt} \right) (L - X) \left(\frac{n}{c} \right).$$

Thus, the change in length indicated by the interferometer is a function of the time derivative of the pressure signal, the number of turns N_{coil} of fiber on the pipe, and the length L of the delay portion of the fiber.

FIG. 6 is a block diagram showing an example of the processing of a received optical signal using interferometer 200. Counter propagating beams 231, 232 travel through optical fiber 230 comprising measurement section 220 and delay section 225. In this example, delay section 225 comprises multiple loops of optical fiber around a spool (not shown). Pressure signal 21 causes a lengthening of measurement section 220 which produces a phase shift in the recombined beams at detector 210, as described previously. Detector 210 outputs a phase shift signal that is conditioned by signal conditioner 312 and outputs as an analog signal proportional to the time derivative of pressure dp/dt at

314. The signal 314 is transmitted to A/D in block 316 where the dp/dt signal is digitized. The digitized dp/dt signal is integrated in block 318 to produce a digital signal similar to the original pressure signal $P(t)$. The $P(t)$ signal is then decoded in block 320 to produce data 216. Data 216 may be used in log modules 324 to produce logs 326. In one
5 embodiment, optical source 202, optical detector 210, and signal conditioner 312 may be physically located close to conduit 211 in signal detector 36. Alternatively, some of these items may be located away from conduit 211, for example in controller 33. The functional modules 316, 318, 320, 324, and 326 may comprise hardware and software and may be located in controller 33. In one embodiment, controller 33 may be a stand
10 alone unit located in a separate location, for example a logging unit. Alternatively, controller 33 may be an integral part of a logging unit using shared hardware and software resources. While described above with reference to a single optical signal detector on a conduit, it is intended that the present disclosure cover any number of such detectors spaced out along such a conduit.

15 FIG. 7 is a chart of laboratory test data showing raw interferometer data and integrated interferometer data compared to conventional pressure sensor data for pressure signal detection. Pressure signals are generated in a flowing fluid in a flow loop. A pressure signal transmitter generates pressure signals into the flowing fluid. An interferometer similar to interferometer 200 is installed on a section of conduit. A
20 conventional strain gauge pressure sensor is mounted within 2 m of the interferometer. FIG. 7 shows the raw interferometer data proportional to dp/dt in curve 700. The raw data is processed as described above to produce an integrated interferometer curve 710. Curve 705 is the reading from the conventional pressure transducer. As shown in FIG. 7, integrated interferometer curve 710 is substantially similar to conventional pressure
25 transducer curve 705.

In one embodiment, an interferometer system, for example interferometer system 200 described above, may be configured as shown in FIG. 8. The system of FIG. 8 has been modularized by using commercially available optical connectors 810 to allow for the use of delay sections 225 of varying properties. For example, different delay modules
30 802 may comprise delay sections 225 of different lengths as described previously.

In another embodiment, FIG. 9 shows an embodiment of signal detector 936 comprising an optical interferometer 900 for detecting pressure signals in conduit 211. In this embodiment, light source 202 emits a light signal 930 into optical splitter/coupler 915 generating beam 931 propagating through first fiber 921 and beam 932 propagating through second fiber 922, having a delay section fiber 925 therein, to a second optical splitter/coupler 916. Beam 931, having taken the short path, L_1 , through first fiber 921, enters and traverses the measurement section 920 having length L_2 , before the second beam 932. Second beam 932 travels through the longer delay section 925, having length L_3 . Beam 931 experiences the strain induced by the pressure signal 21 passing through the section. Second beam 932 having gone through the delay section 925, enters the measurement section 920 at a later time than beam 931, and senses the strain of the measurement section 920 at a later time than beam 931, and senses the strain of the measurement section 925 during at a second time after the passage of the first beam 931. Measurement section fiber 920 has a reflector 935 at its termination such that the signal beams 931, 932 are reflected back toward the second splitter/coupler 916. Reflector 935 may be a mirror affixed to the end of the measurement section fiber 920. Each of the reflected beams 931, 932 coming out of the measurement section 920 will encounter the second splitter/coupler 916. The reflected beams of interest travel through the alternate fiber sections on the reverse path. That portion of first beam 931 which travels through the second fiber 922 including delay section 925 on the return trip, and that portion of the second beam 932 which travels through first fiber 921, when recombined at first splitter/coupler 915, will have each traversed substantially the same total optical path length, differing by the relatively small strain difference of the measurement section during the passage of each beam. The combination of these reflected beams will contain the phase information indicative of the time derivative of the change in the length of the measurement section caused by the passage of pressure signal 21. It is noted that other beam paths are possible. For example, a second combination of path lengths would include beam 931 traversing straight down fibers 921 and 920 and reflecting back over the reverse path, resulting in a path length of $2L_1 + 2L_2$. Similarly, beam 932 may traverse down through second fiber 922, with delay section 925, and measurement section 920 and return through the same fibers, resulting in a path length of $2L_3 + 2L_2$. The second fiber with delay section 925 may be much greater in length than first fiber

section 921. Therefore, there may be a substantial difference in path lengths between the second combination and the desired measurement combination of paths lengths. One skilled in the art of interferometric measurements will appreciate that the coherence length of the light source may be chosen, or adjusted, such that only the desired portions of the reflected beams 931, 932 can be made to interfere at optical detector 210. For example, the coherence length is a function of the optical source and the fiber characteristics. The coherence length is a measure of the difference in path lengths of the two beams at which interference patterns may still be measured. By selecting, or adjusting, the optical source such that the coherence length is greater than the small difference in the desired measurement paths, but less than the difference between the second path length combination, the interference signals from the second combination of paths may be substantially eliminated. The other possible path combinations may be similarly eliminated from consideration.

FIG. 10 shows a modularized example of the system of FIG. 9. For example, available optical connectors 810 are inserted to allow for the use of delay sections 225 of varying properties. For example, different delay modules 902 may comprise delay sections 225 of different lengths as described previously.

FIG. 11 shows an embodiment of an optical fiber measurement section 1110 wrapped around a conduit 1111 for detecting pressure pulses propagating in a fluid in conduit 1111. For example, conduit 1111 may be standpipe 11 of FIG. 1 that has a drilling fluid flowing therein. Measurement section 1110 may be substantially interchangeable with measurement section 220, described above. Measurement section 1110 comprises an optical fiber 1120 adhered to a flexible band 1115 with a flexible protective layer 1116 over the optical fiber and also adhered to the flexible band 1115. Measurement section 1110 also comprises fasteners 1125 to hold the measurement assembly tightly around conduit 1111. As described previously, pressure pulses in conduit 1111 cause circumferential strains in conduit 1111 that are coupled through flexible band 1115 to optical fiber measurement loop 1120. The strains cause changes in the length of optical fiber 1120 in the portions aligned circumferentially around conduit 1111. These changes in length of optical fiber 1120 may be detected, in real time, by any of the interferometer techniques described above, and related to the pressure pulses in

conduit 1111. Optical connectors 1130 may be attached to each end of optical fiber 1120 to facilitate connection to the interferometer systems described above.

FIG. 12 shows an exploded view of a portion of one embodiment of measurement section 1110. In one example, flexible band 1115 may be a flexible plastic film material. Plastic film materials include, but are not limited to: a polyethylene terephthalate material, a polyimide material, a polypropylene material, a polyurethane material, and any other suitable plastic material. In one embodiment, the band may have a thickness of about 0.02mm to about 0.3 mm. Alternatively, flexible band 1115 may comprise a flexible metal material.

In one example, optical fiber 1120 may be about 3m to about 10m long. As shown in FIG. 11, optical fiber 1120 comprises multiple continuous windings, also called loops, of the optical fiber such that the measurement section 1110 provides approximately one wrap of the optical fiber loops around conduit 1111. In one example, the optical fiber is formed on flexible band 1115 at location 1120a using a fixture described below. A suitable flexible adhesive, for example, a urethane adhesive is applied to adhere the optical fiber loop 1120 to flexible band 1115. Protective layer 1116 is adhesively attached over optical fiber measurement loop and is adhered to flexible band 1115 to protect optical fiber 1120 from ambient contaminants, for example, dirt, oil, grease, and water. Protective layer 1116 may be any of the plastic materials discussed above.

FIG. 13 shows optical fiber measurement section 1110 rolled out flat as it appears after fabrication. In the embodiment shown here, fasteners 1125 a and 1125b are hook and loop type fasteners. As shown, fastener 1125a is mounted on a top surface of protective layer 1116, and fastener 1125b is mounted on a bottom surface of flexible band 1115. At installation, the measurement section 1110 is wrapped around the conduit with the flexible band between the conduit and the optical fiber. Any other suitable fasteners may be used to firmly secure measurement section 1110 around conduit 1111. In one example, optical fiber measurement section 1110 may be wrapped around conduit 1111 and secured with a suitable adhesive tape.

Referring to FIGS. 14A and 14B, one embodiment is shown of a fixture assembly 1310 for fabricating an optical fiber measurement assembly, as described above. Baseplate 1210 has at least two lengthwise spaced-apart holes 1212 for mounting optical

fiber guide assemblies 1213 thereto. Fiber guide assembly 1213 comprises a guide disc 1215 fixed to baseplate 1210 by fastener 1220, washer 1217 and nut 1218. Guide disc 1215 has an undercut shoulder 1230 having a diameter greater than a critical bend diameter of optical fiber 1120. Undercut shoulder 1230 has a height, h , and width, w , such that multiple wraps of optical fiber 1120 may be assembled around shoulder 1230 and maintained in a substantially flat condition against baseplate 1210. Height, h , and width, w , may be selected based on the particular dimensions of a particular optical fiber 1120 to be used.

In operation, flexible band 1115 is laid flat, and fixed to baseplate 1210 with, for example, an adhesive tape. Suitable guide discs 1213 are installed over flexible band 1115. Distance, d , between the centers of guide discs 1215 is selected such that it corresponds to approximately the circumference of the conduit selected for installation. Optical fiber 1120 is wound around guides 1215 as shown. As indicated previously, optical fiber 1120, may be from about 1m to about 10m in length. Optical fiber 1120 is lightly tensioned during installation to ensure that there is no slack in the optical fibers. In one example, a manually applied tension of about 1- 10lbf (4.5-45N) is applied. After winding the optical fiber into multiple loops 1121, the loops may be adhered to flexible band 1115 by application of a flexible adhesive 1123 over the loops 1121. Alternatively, an adhesive tape may be used to fix loops 1121 to flexible band 1115. Guide disc assemblies 1213 are removed from baseplate 1210 and a protective layer 1116 may be installed over fiber loops 1121 and adhered to flexible band 1115. In one example, fasteners 1125a and 1125b are then attached.

In another embodiment, see FIG. 15A-C, an optical fiber measurement section 1500 may comprise a flexible metal band 1505 having hook ends 1510. Assembly of the measurement section is similar to that described above. FIG. 15B shows the installation of the measurement assembly 1500 on conduit 1501. Flexible metal band 1505 is placed around conduit 1501, and clamp assembly 1530 engages hook ends 1510. Clamp members 1520 are drawn together by threaded member 1522 that is threaded into nut 1526. Spring 1523 acts between handle 1521 and clamp member 1520 to impart a predetermined tension on hook ends 1510. The predetermined tension forces the flexible

metal band firmly against the outer surface of conduit 1501 and allows circumferential strains in conduit 1501 to be transmitted to optical fiber 1120.

FIG. 16 shows another example of an optical fiber measurement section 1600 that comprises a hinged clamp 1601 sized to closely fit around a conduit, for example conduit 11 of FIG. 1. Hinged clamp comprises semi-circular clamp members 1605 and 1606 attached through hinge 1610. An open edge of each clamp member 1605 and 1606 has a plurality of guide members 1625 attached thereto, such that the guide members 1625 are free to swing inward when the clamp members are closed around conduit 11. In one example, guide member 1625 may be a pulley. At least one guide member is supported by a spring 1626. An optical fiber 1120 is threaded through the guide member forming a web across the open plane when clamp 1601 is in the open position. Optical fiber 1120 is lightly tensioned during assembly to remove any slack in optical fiber 1120. When clamp 1600 is closed around conduit 11, optical fiber 1120 conforms to the circumference of conduit 11 and optical fiber 1120 is held firmly around conduit 11 when clamp members 1605 and 1606 are closed around conduit 11. Clamp members 1605 and 1606 may be fixed around conduit 11 by buckles 1615. Alternatively, hose clamps or tie wraps may be fixed around clamp members 1605 and 1606 to hold them firmly around conduit 11.

FIG. 17, shows a measurement section 1710, similar in construction to measurement section 1110, and suitable for use as measurement section 920 described in FIG. 10. Measurement section 1710 comprises a reflector 1735, for example a mirror, optically coupled to one end of optical fiber 1120 to facilitate the interferometer system as described with respect to FIG. 10. Alternatively, reflector 1735 may comprise a polished end of measurement section fiber 920. The polished end may have a reflective material deposited thereon. Suitable reflective materials include, but are not limited to: gold, silver, aluminum, and copper. Connector 1130 may be connected to the other end of optical fiber 1120. Other features may be similar to those described with respect to measurement section 1110.

Numerous variations and modifications will become apparent to those skilled in the art. It is intended that the following claims be interpreted to embrace all such variations and modifications.

What is claimed is:

1. An apparatus to detect a pressure signal in a fluid flowing in a conduit comprising:
 - a flexible band sized to fit at least partially around the conduit;
 - 5 an optical fiber flexibly adhered to the flexible band; and
 - at least one fastener attached to the flexible band to fasten the flexible band at least partially around the conduit.
2. The apparatus of claim 1 wherein the optical fiber is formed into a continuous plurality of loops.
- 10 3. The apparatus of claim 1 further comprising a protective layer flexibly adhered over the optical fiber.
4. The apparatus of claim 1 wherein the flexible band is made of a material selected from the group consisting of: a polyethylene terephthalate material, a polyimide material, a polypropylene material, a polyurethane material, and a metal material.
- 15 5. The apparatus of claim 1 wherein the at least one fastener is a hook and loop fastener.
6. The apparatus of claim 1 further comprising an optical interferometer optically coupled to the optical fiber to detect a strain induced change in the optical fiber related to the pressure signal in the fluid flowing in the conduit.
- 20 7. The apparatus of claim 1 further comprising an optical reflector optically coupled to one end of the optical fiber.
8. A method for detecting a pressure signal in a conduit comprising:
 - adhering an optical fiber to a flexible band;
 - attaching at least one fastener to the band; and
 - 25 fastening the band around the conduit such that a strain induced in the conduit by the pressure signal is transmitted to the optical fiber.
9. The method of claim 8 further comprising optically coupling an optical interferometer to the optical fiber and detecting an interference signal related to the strain induced in the conduit by the pressure signal and generating an output
30 signal related thereto.

10. The method of claim 9 further comprising integrating the output signal with respect to time and generating a second output signal substantially similar to the fluid pressure signal in the conduit.
11. The method of claim 8 further comprising adhering a flexible protective layer
5 over the optical fiber.
12. The method of claim 8 further comprising optically coupling a reflector to an end of the optical fiber.
13. A method for assembling an optical fiber measurement section comprising:
fixing a flexible band to a baseplate;
10 winding a plurality of loops of a continuous optical fiber around a pair of spaced apart guide discs attached to the baseplate;
attaching the plurality of loops to the flexible band with a flexible adhesive;
adhering a protective layer over the plurality of loops to the flexible band;
15 and
attaching at least one fastener to the flexible band.
14. The method of claim 13 further comprising applying a predetermined tension to the continuous optical fiber during the winding of the loops.
15. The method of claim 13 wherein winding a plurality of loops of a continuous
20 optical fiber further comprises winding the plurality of loops around a pair of spaced apart guide discs attached to the baseplate.
16. An apparatus to detect a pressure signal in a fluid flowing in a conduit comprising:
a first substantially semi-circular clamp member attached to a second
25 substantially semi-circular clamp member by a hinge;
a plurality of guide members disposed in a spaced apart arrangement along an edge of each of the first and second clamp members;
an optical fiber threaded through the plurality of guide members to form a web across an opening formed by open first and second clamp members such that
30 the optical fiber conforms to the circumference of the conduit when the first and second clamp members are closed around the conduit; and

at least one fastener for fastening the first and second clamp members around the conduit.

17. The apparatus of claim 16 wherein the plurality of guide members comprise a plurality of pulleys.

5 18. The apparatus of claim 16 further comprising at least one spring supporting at least one guide member.

19. The apparatus of claim 16 further comprising an optical interferometer optically coupled to the optical fiber to detect a strain induced change in the optical fiber related to the pressure signal in the fluid flowing in the conduit.

10 20. The apparatus of claim 16 wherein the fastener is a buckle.

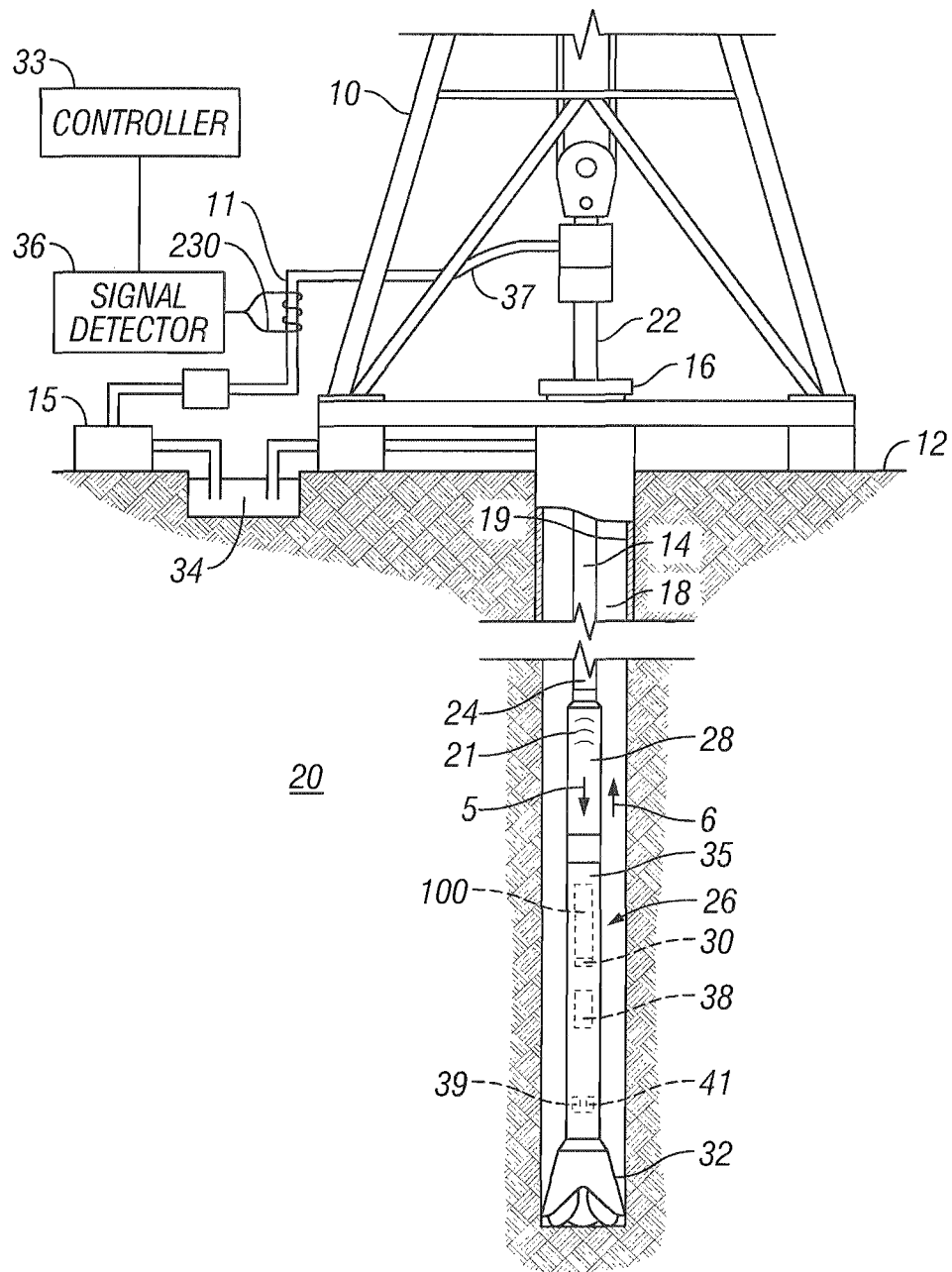


FIG. 1

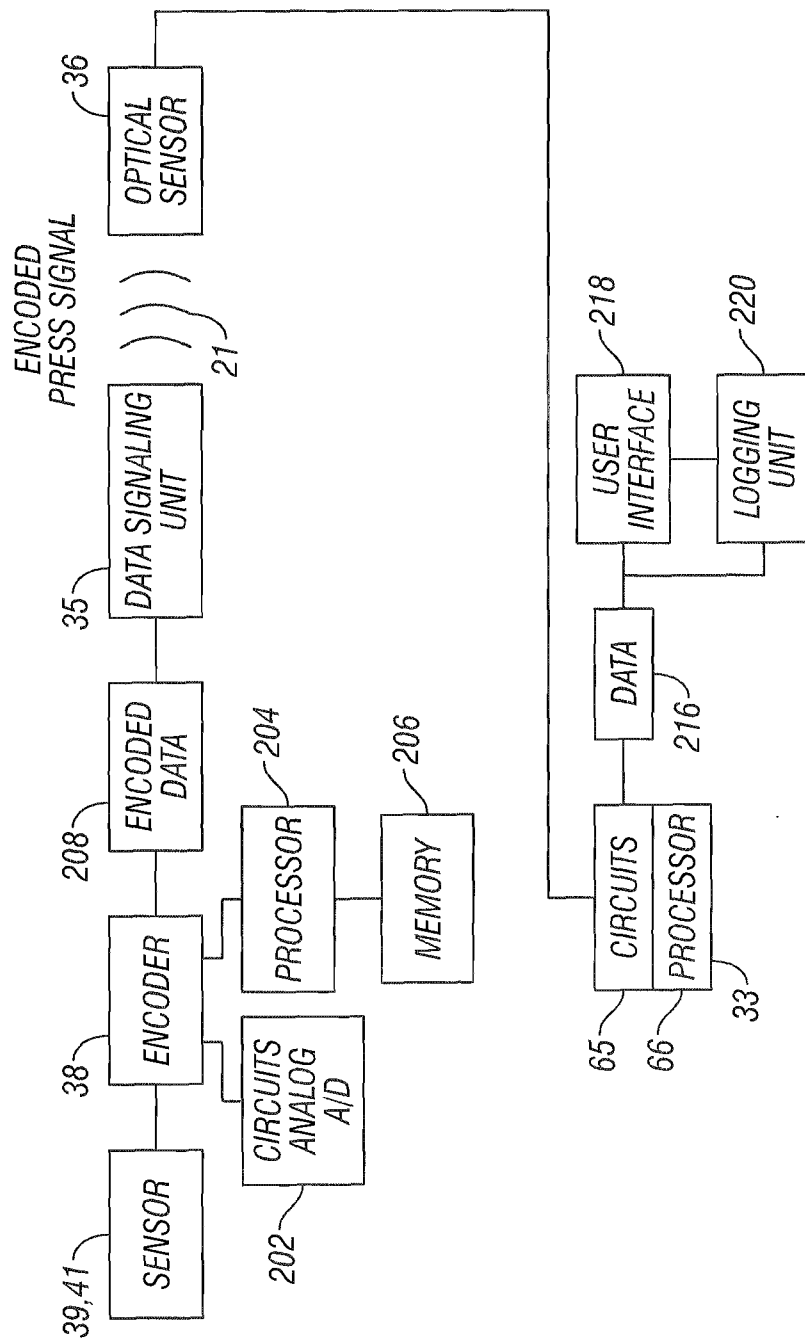


FIG. 2

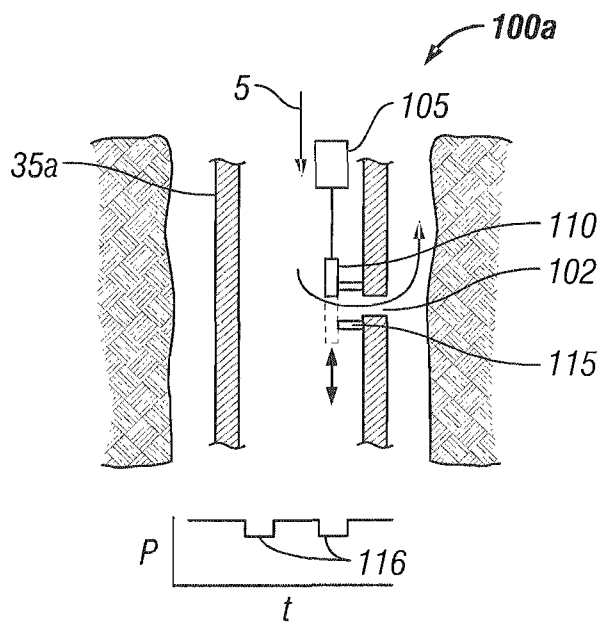


FIG. 3A

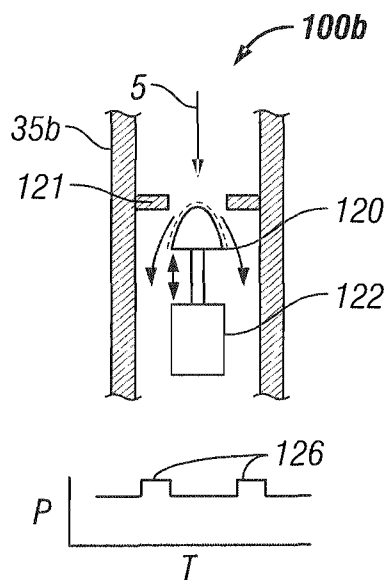


FIG. 3B

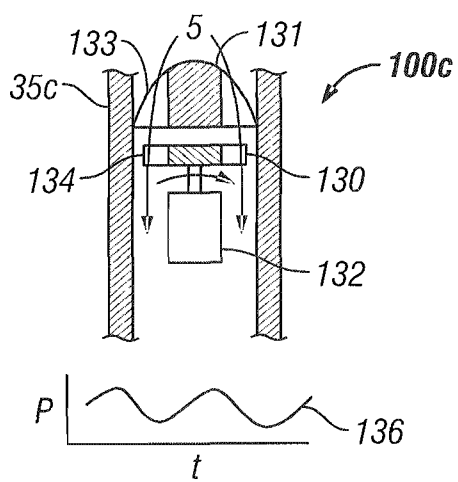


FIG. 3C

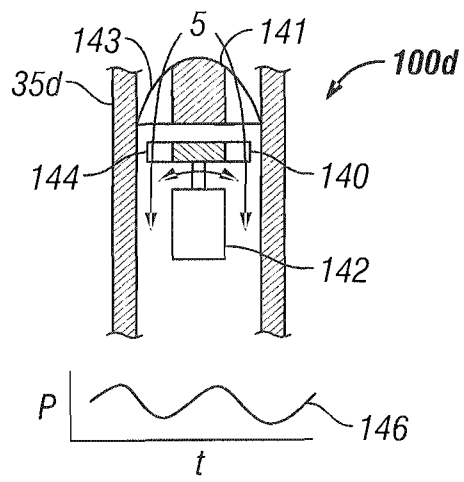


FIG. 3D

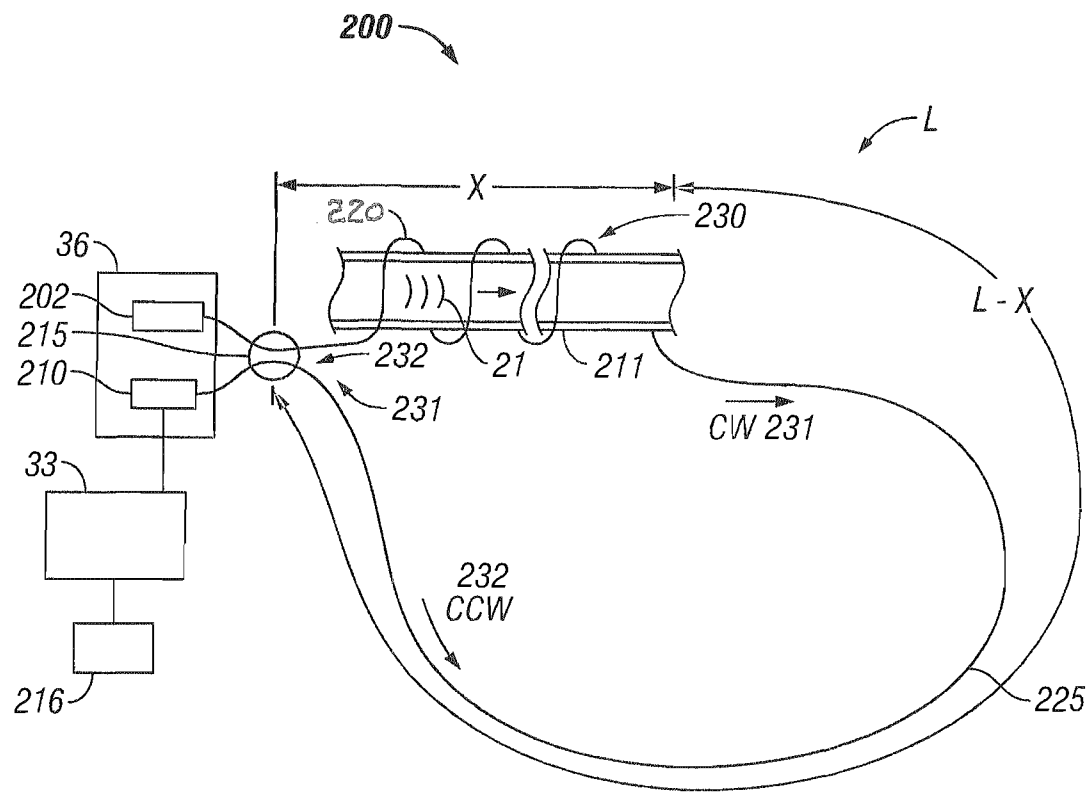


FIG. 4

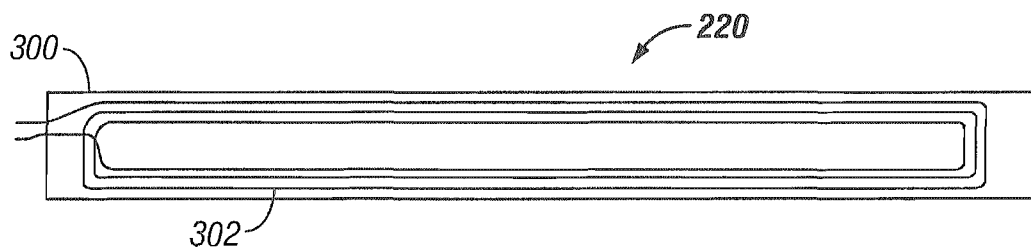


FIG. 5

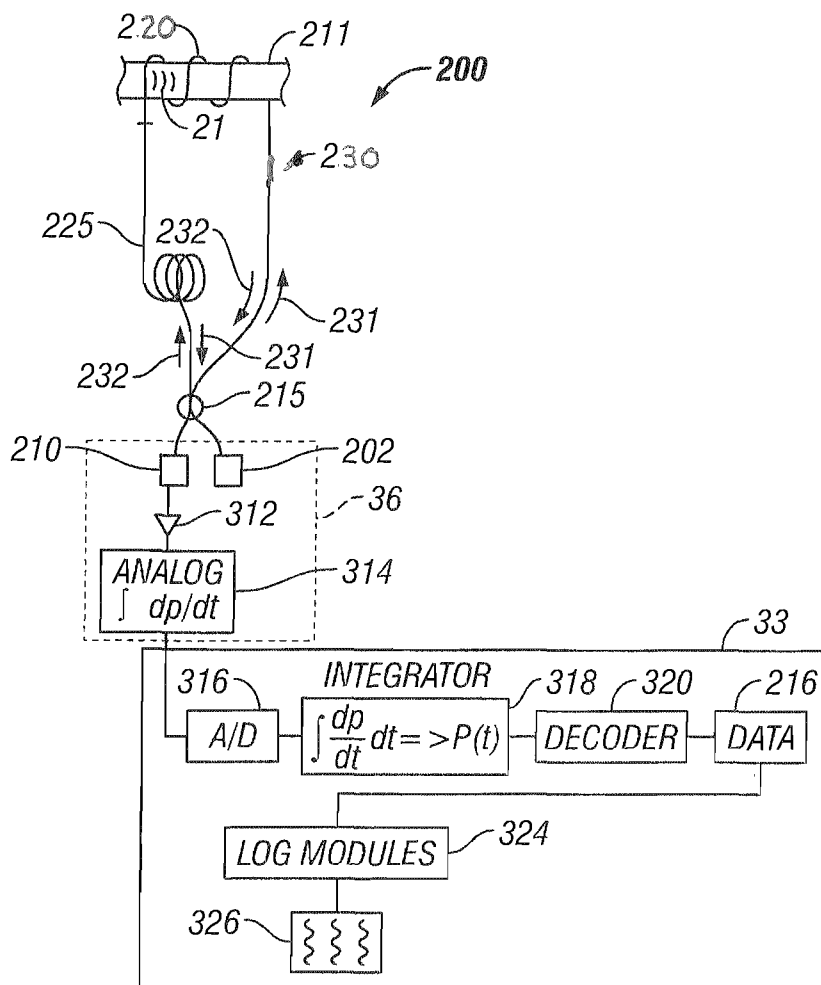


FIG. 6

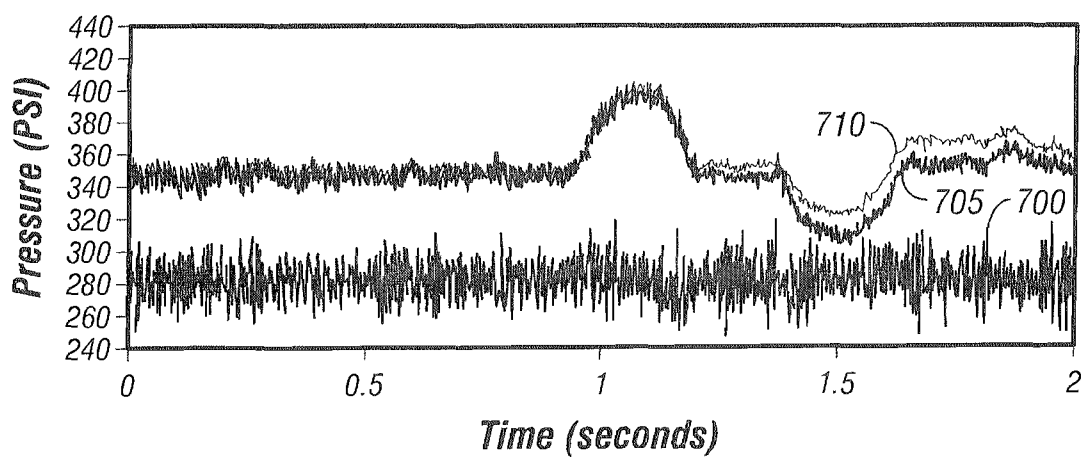


FIG. 7

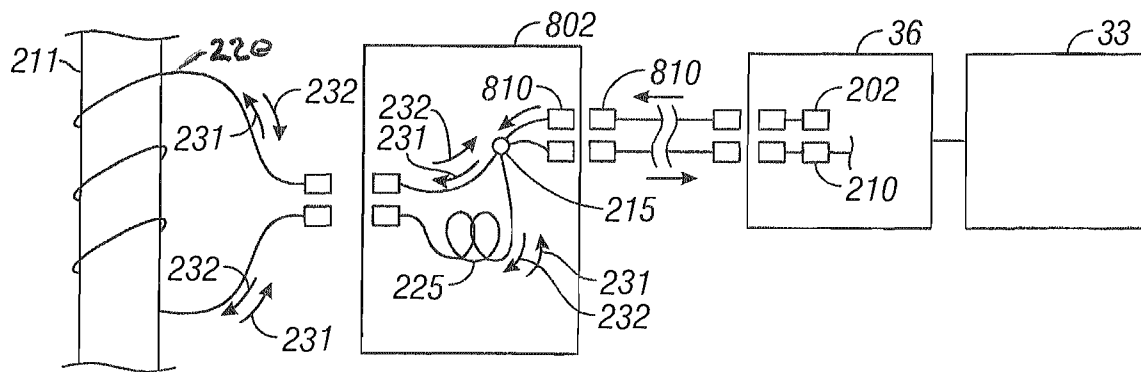


FIG. 8

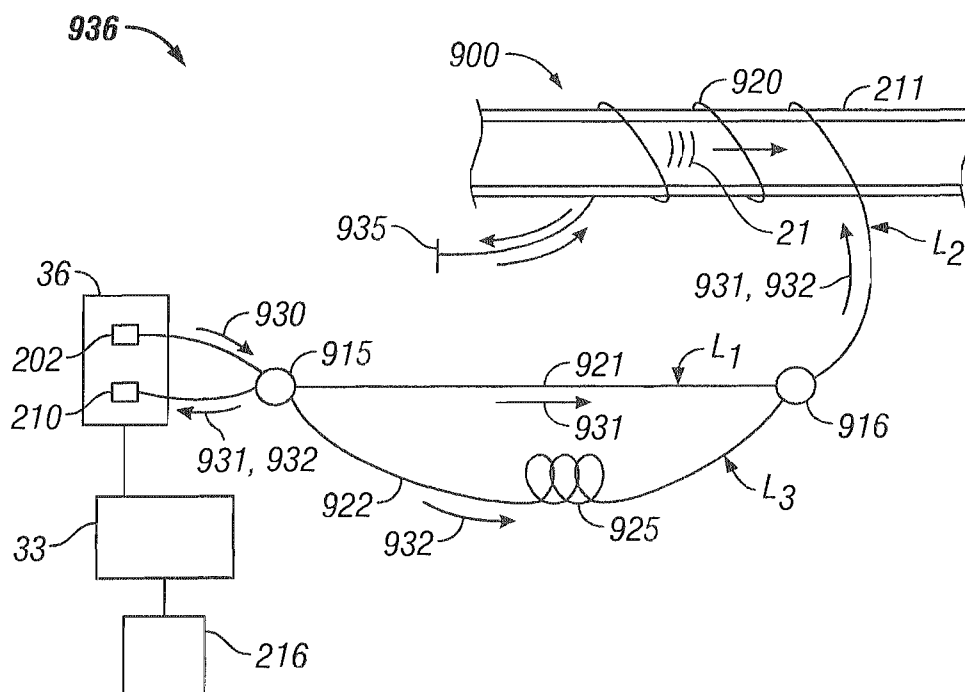
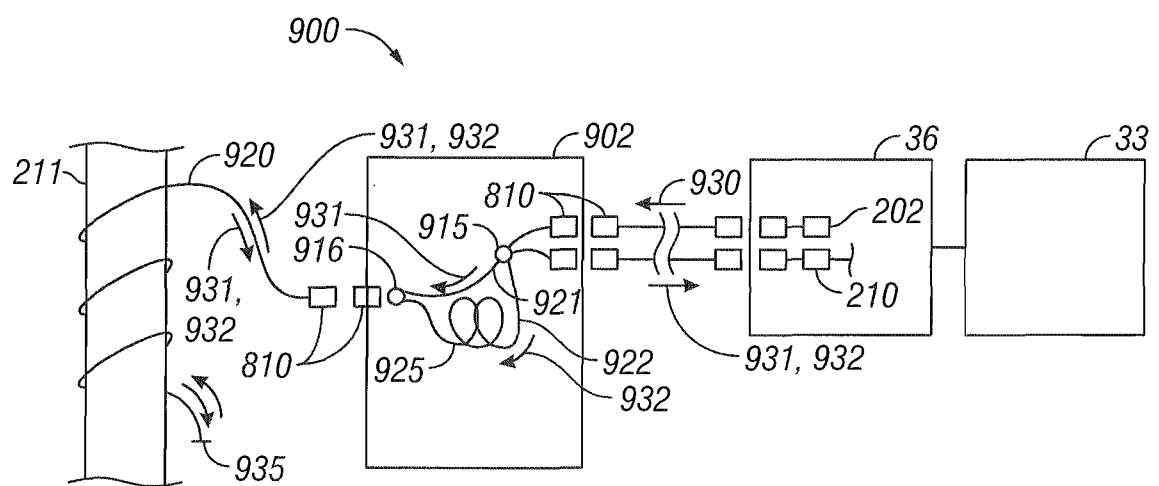


FIG. 9

**FIG. 10**

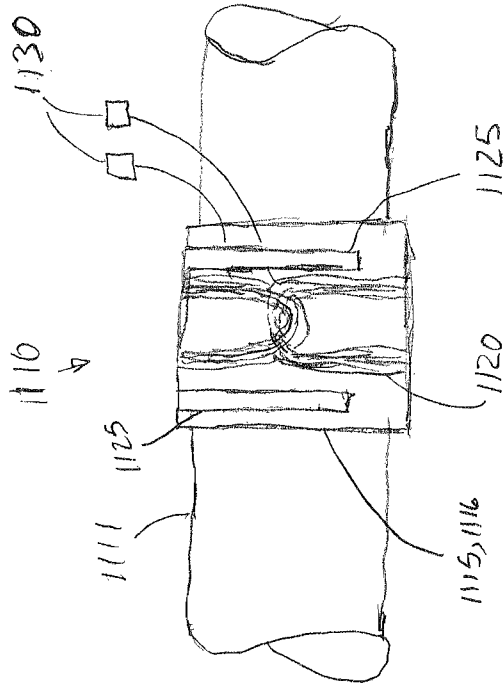


FIG. 11

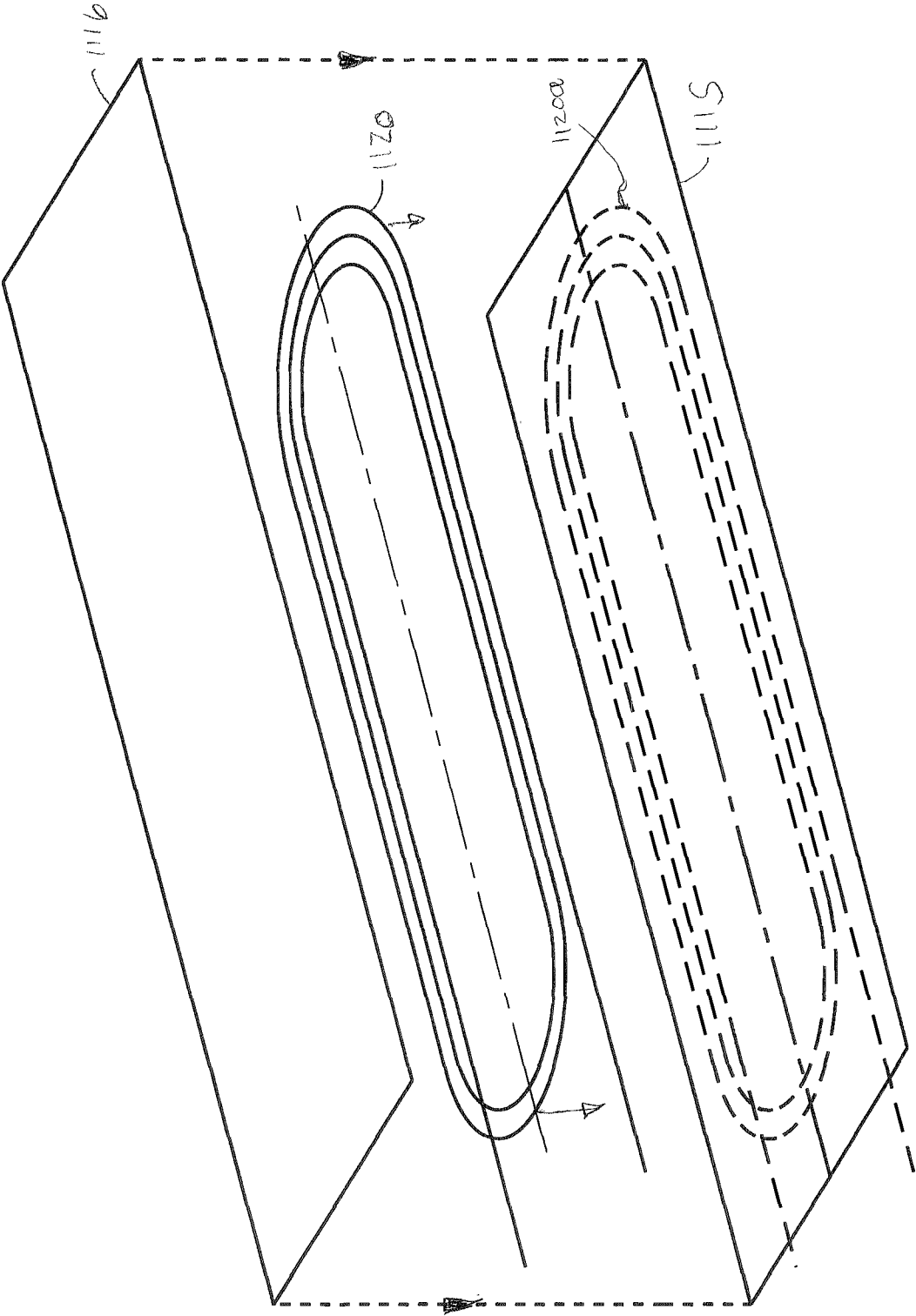


FIG. 12

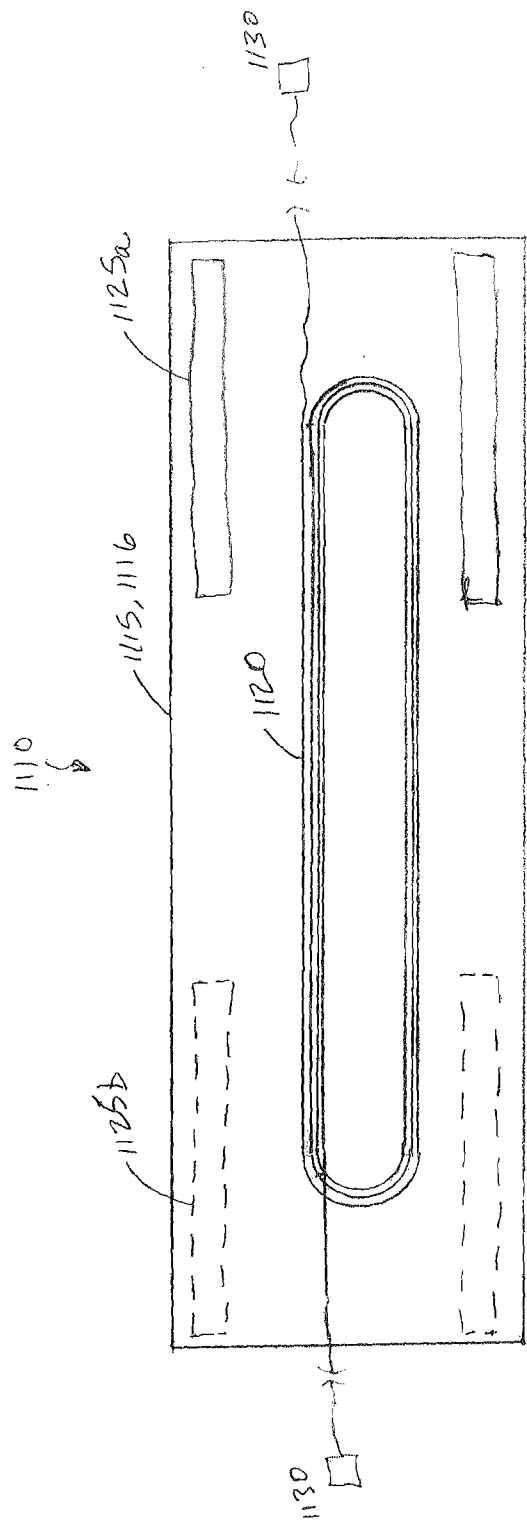
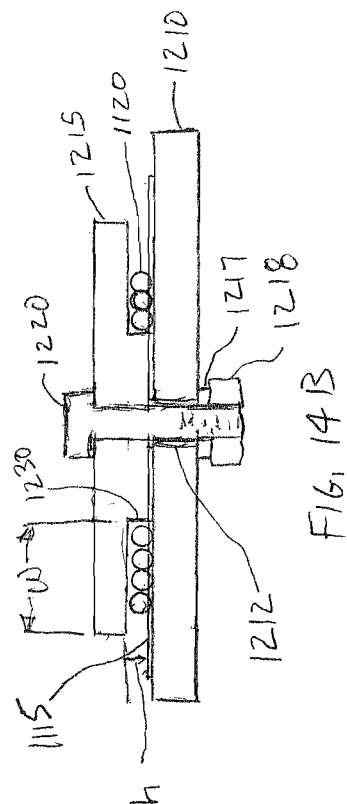
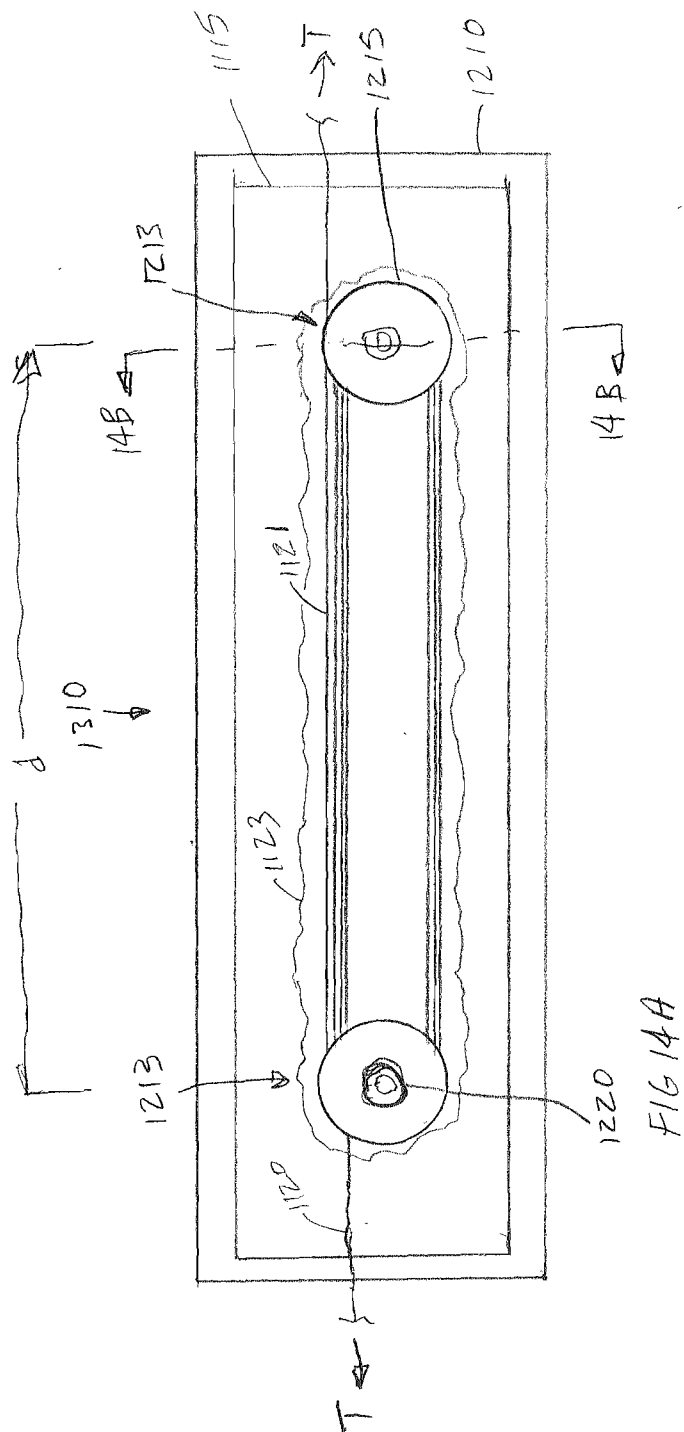


FIG. 13



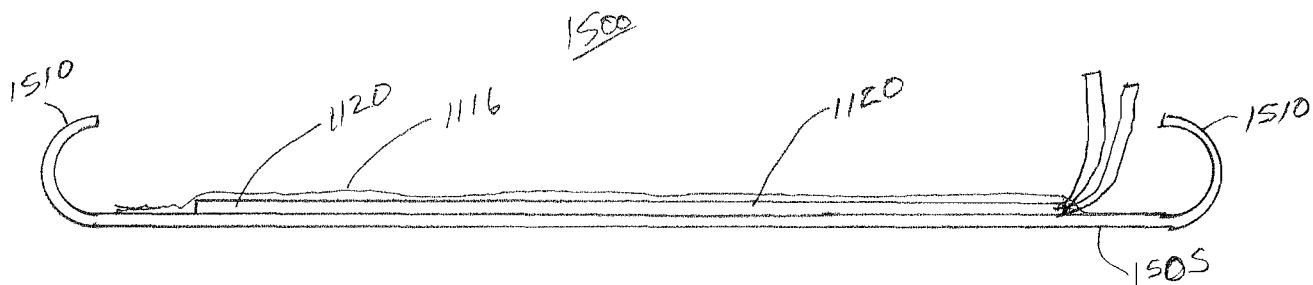


FIG. 15A

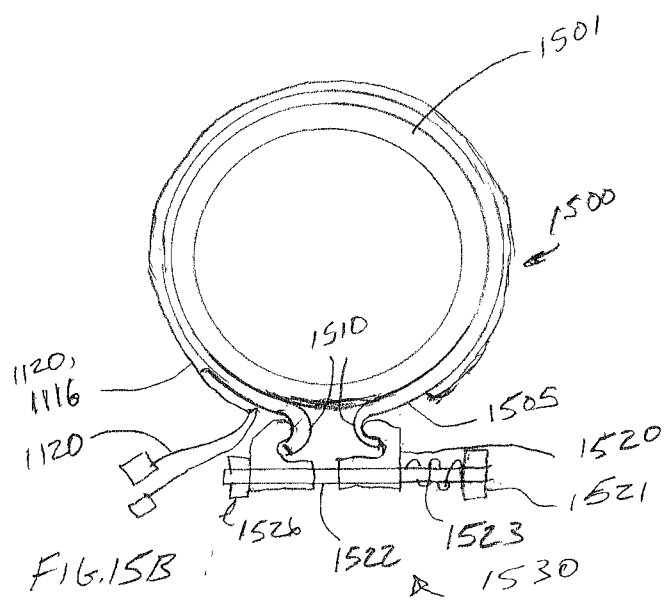


FIG. 15B

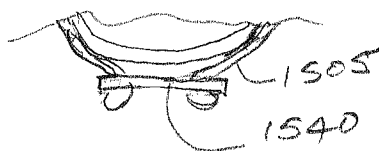


FIG. 15C

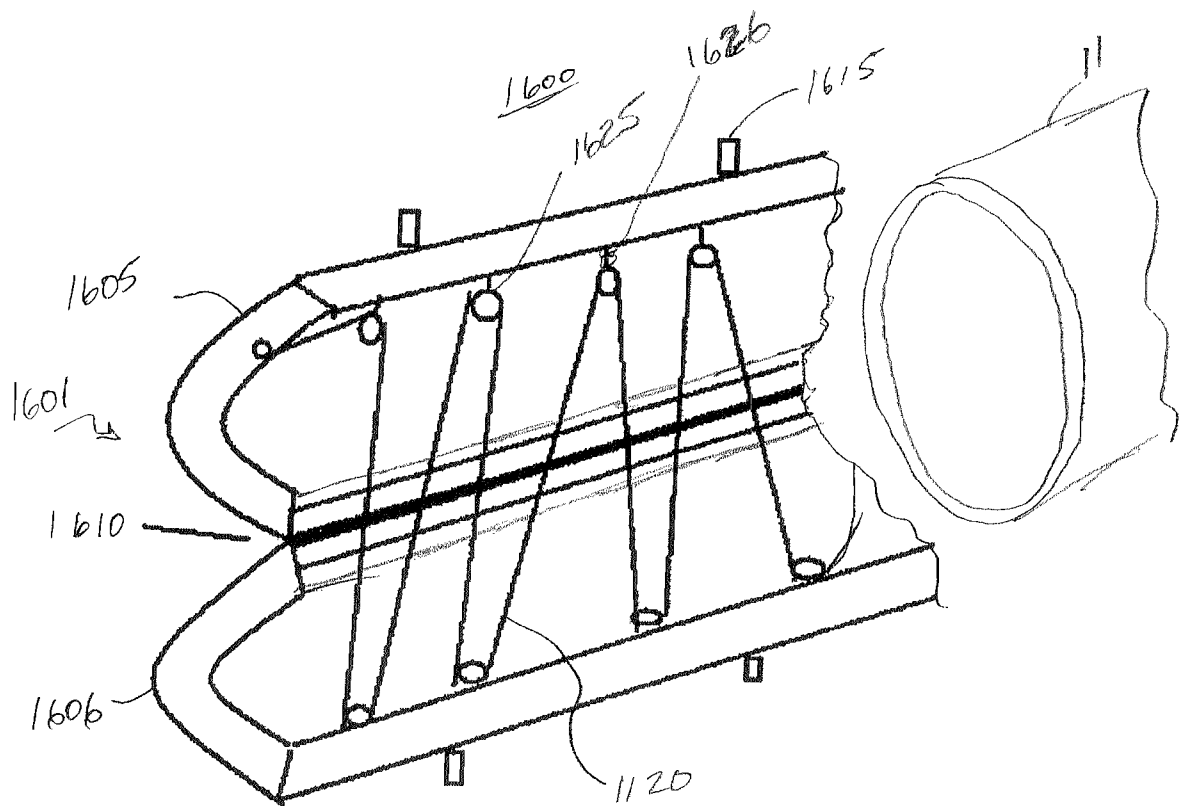


FIG. 16

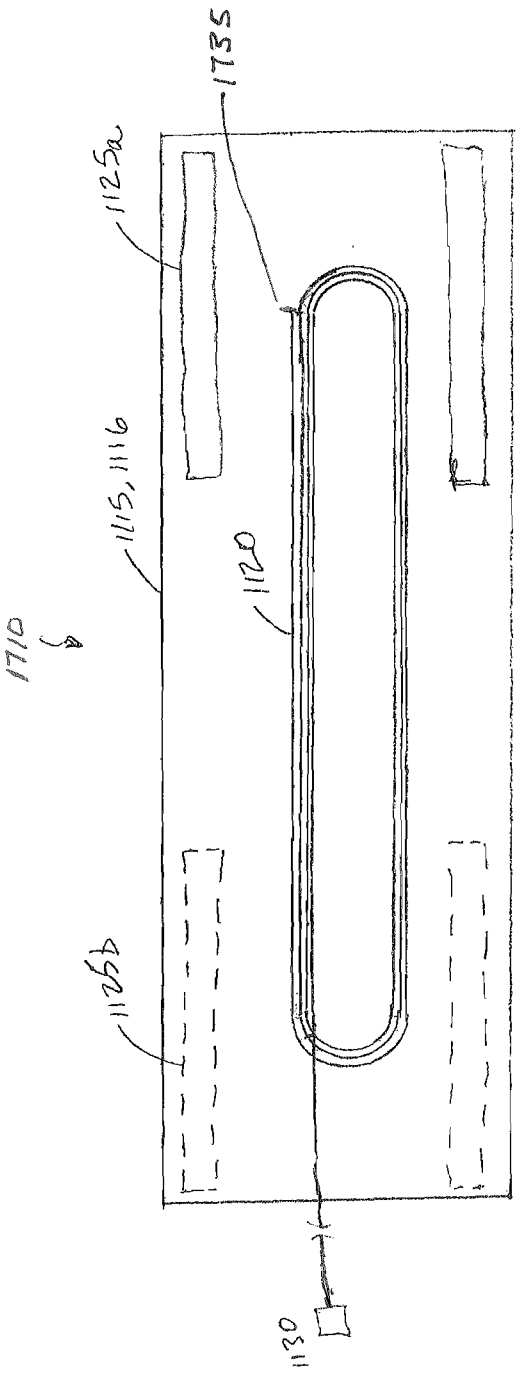


FIG. 17

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2009/050628

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G01D 5/353 (2009.01)

USPC - 250/227.14

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - G01D 5/34, 5/35, 5/353 (2009.01)

USPC - 73/1.35, 1.71, 152.32; 138/118, 123; 166/206, 236, 242.2, 277; 250/216, 221, 227.14, 227.19, 256; 356/480

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PatBase

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ---	US 2006/0001863 A1 (KISHIDA et al) 05 January 2006 (05.01.2006) entire document	1, 4-5, 8
Y		2-3, 6-7, 9-15
X ---	US 2007/0289741 A1 (RAMBOW) 20 December 2007 (20.12.2007) entire document	16-17, 20
Y		18-19
Y	US 5,649,035 A (ZIMMERMAN et al) 15 July 1997 (15.07.1997) entire document	2-3, 11, 13-15
Y	US 2001/0032924 A1 (PRAMILA et al) 25 October 2001 (25.10.2001) entire document	6-7, 9-10, 12, 14
Y	US 6,535,684 B1 (KONDO et al) 18 March 2003 (18.03.2003) entire document	13-15
Y	US 4,633,079 A (RIEGER) 30 December 1986 (30.12.1986) entire document	18

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

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

28 August 2009

Date of mailing of the international search report

08 SEP 2009

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