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(56) Documents Cited:
GB 2491658 A **WO 2013/030555 A2**
WO 2012/084997 A2 **WO 2012/068558 A1**
US 20130329522 A1 **US 20130021615 A1**

(58) Field of Search:
INT CL **E21B, G01D, G01H**
Other: **EPODOC, WPI, TXTE**

(54) Title of the Invention: **Method and system for determining downhole object orientation**
Abstract Title: **Downhole optical fiber acoustic orientation tool.**

(57) A method and tool used for determining the orientation of a downhole object, comprising providing the downhole object with a high frequency highly directional sound source 36 fixed in known relation to the object; operating the high frequency directional sound source; rotating the downhole object; and detecting the high frequency directional sound source using an optical fiber 56 acoustic sensing system 58 deployed downhole when the high frequency directional sound source is pointing at the optical fiber; wherein the rotational orientation of the downhole object with respect to the optical fiber is determined based on the detection of the sound source and the known fixed relation between the sound source and the object and the tool comprises an optical interferometer 58, which may be described as a DAS or distributed acoustic sensing system, arranged to detect optical backscatter signals from the optical fiber. In preferred embodiments the sound source is an ultrasonic source 36 operating at in excess of 100 kHz, and the optical fiber acoustic sensing system operates in a continuous wave mode of operation to be able to detect the high frequencies. The object being detected may be a perforating gun 32.

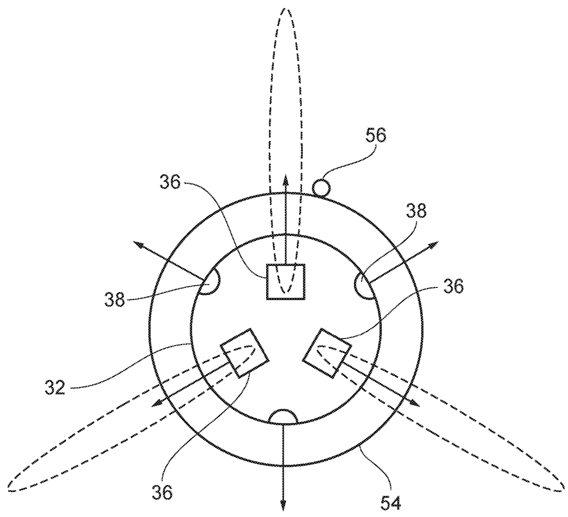

FIG. 4

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

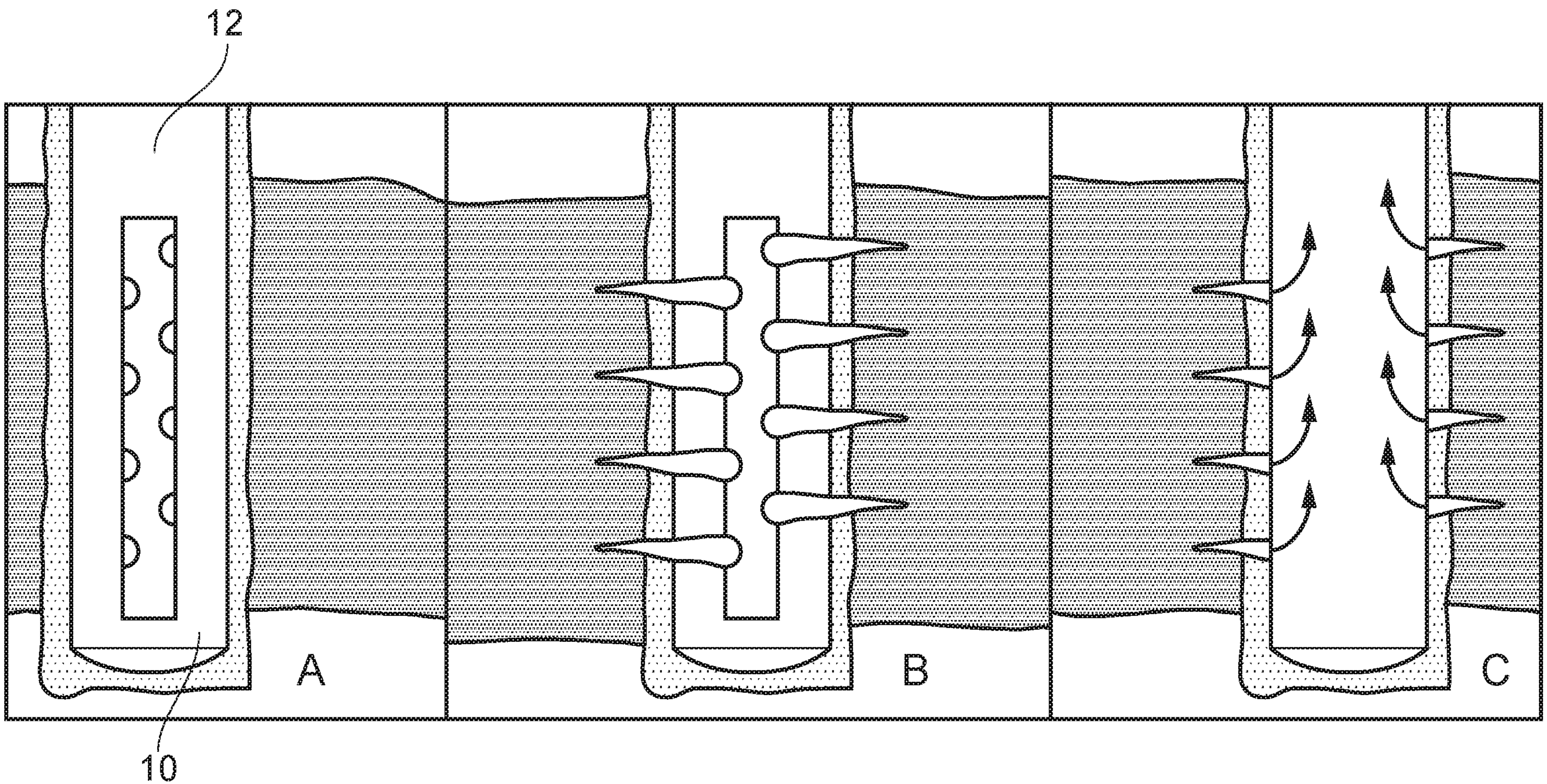

FIG. 1 (Prior Art)

27 02 15

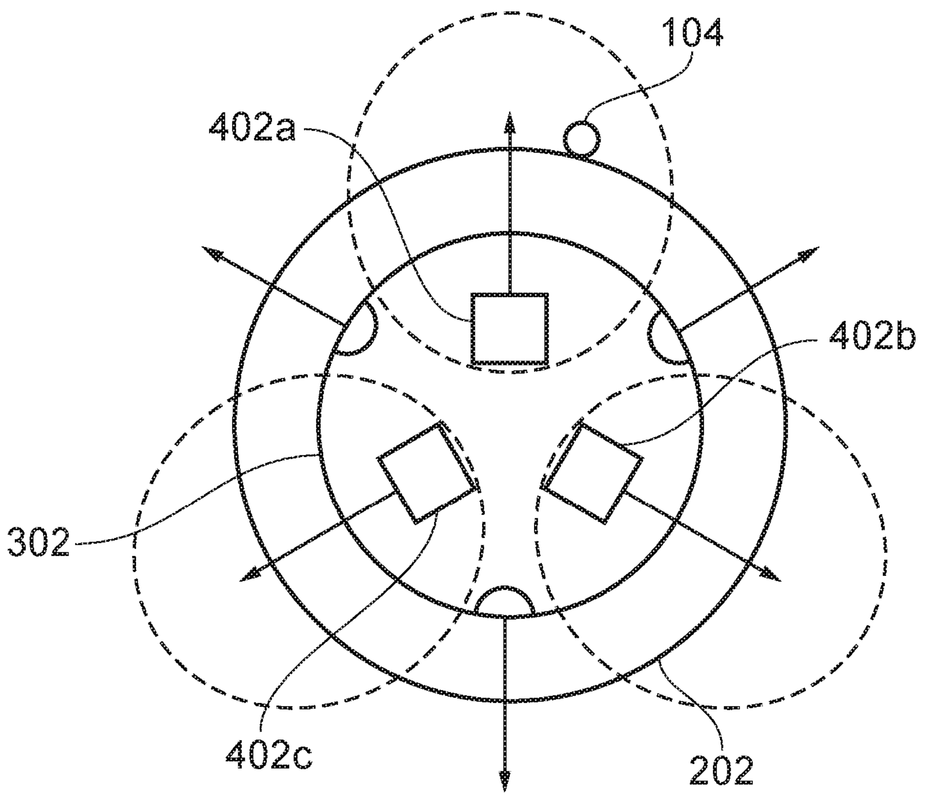

FIG. 2 (Prior Art)

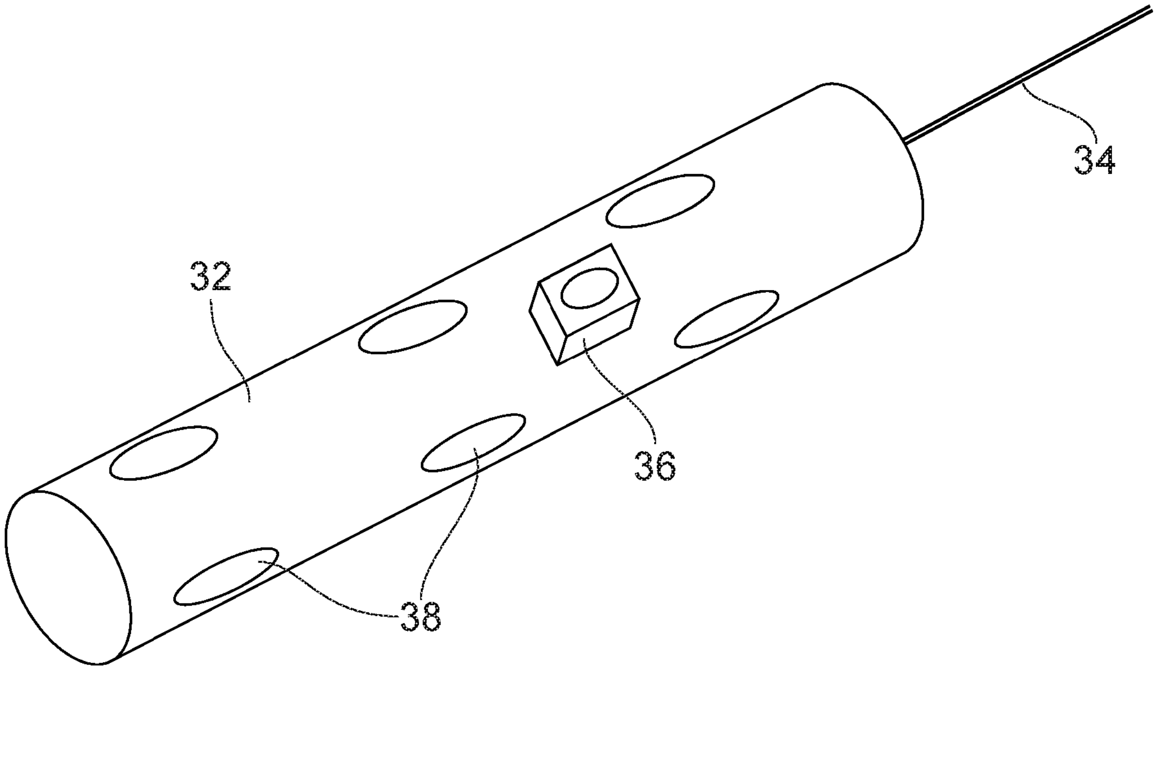

FIG. 3

27 02 15

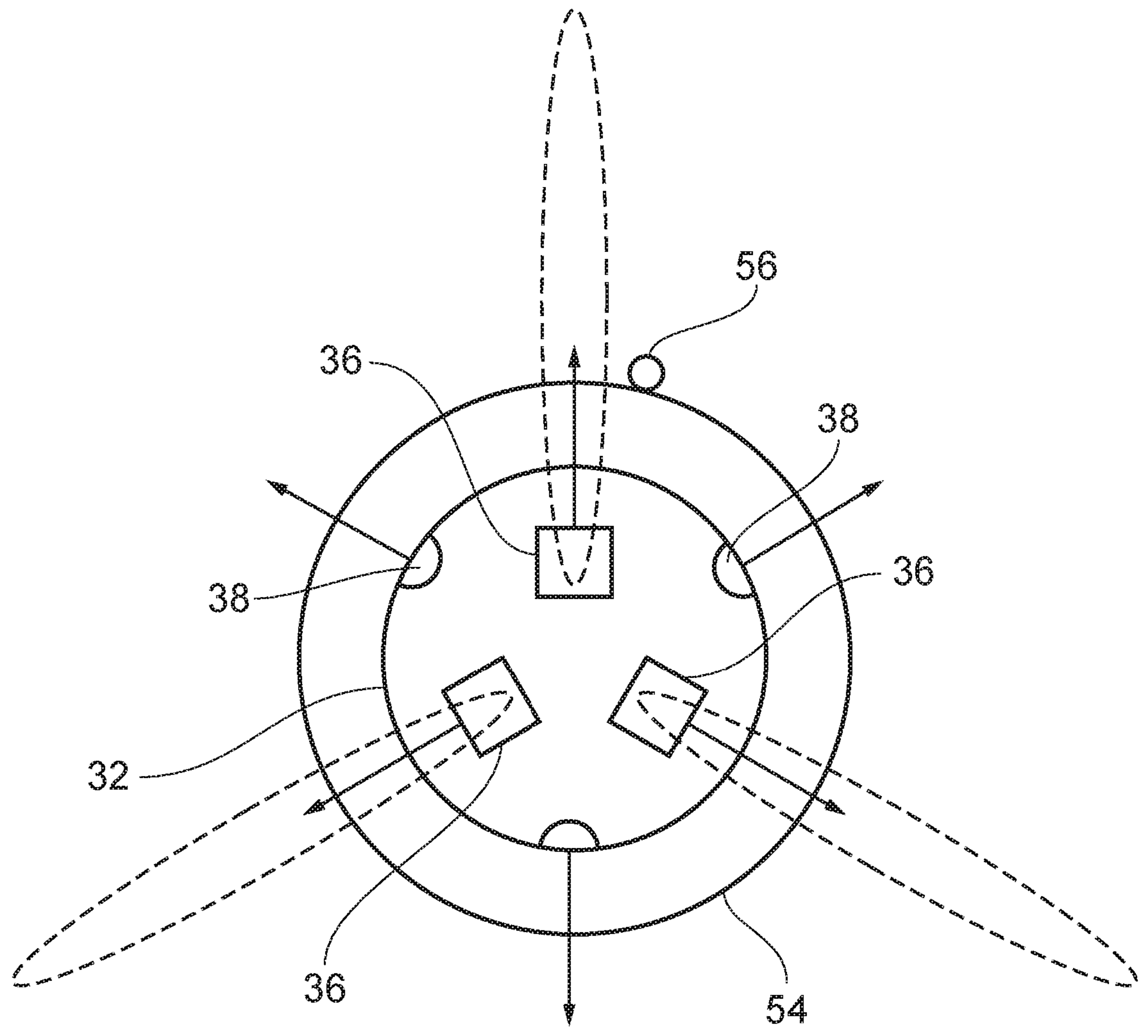

FIG. 4

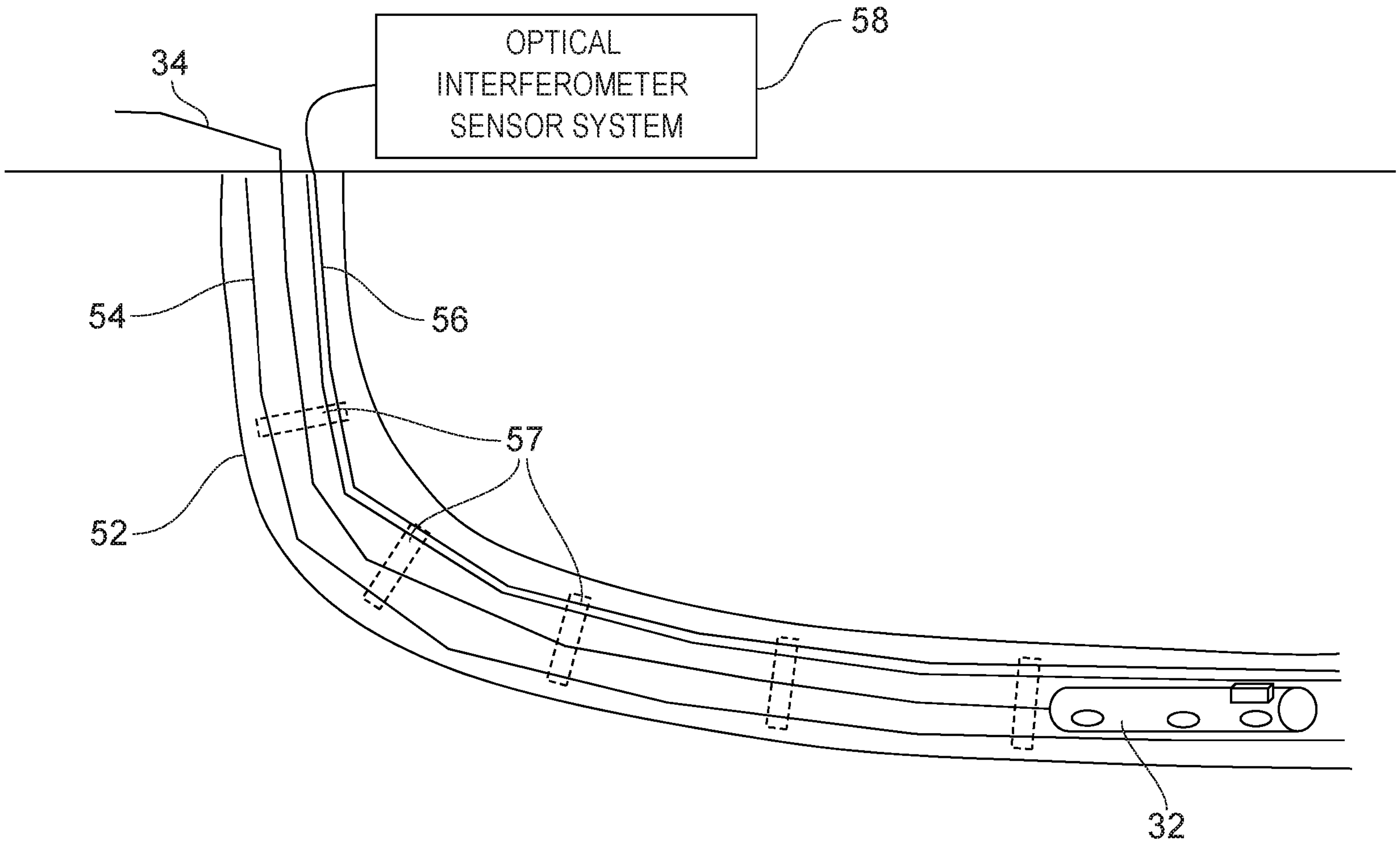

FIG. 5

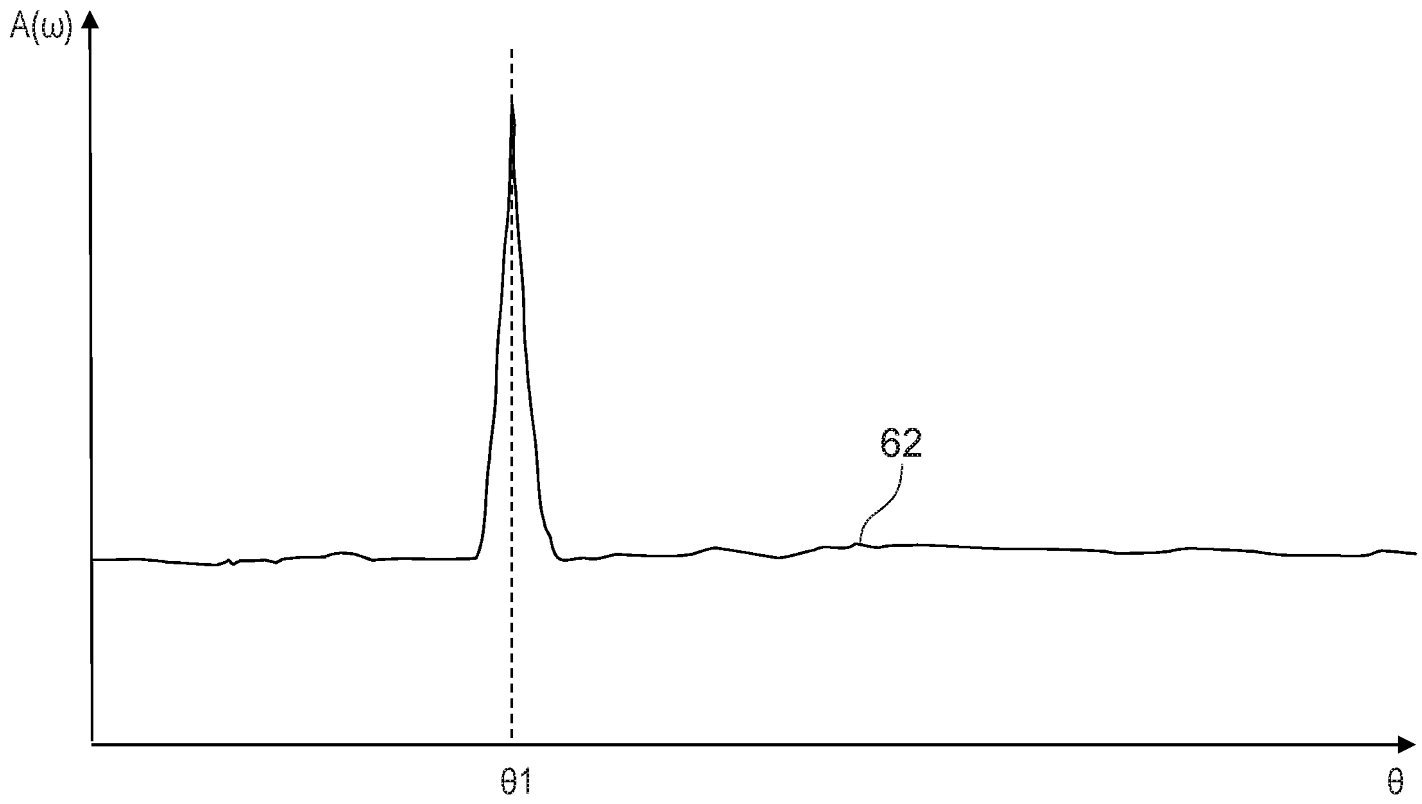

FIG. 6

27 02 15

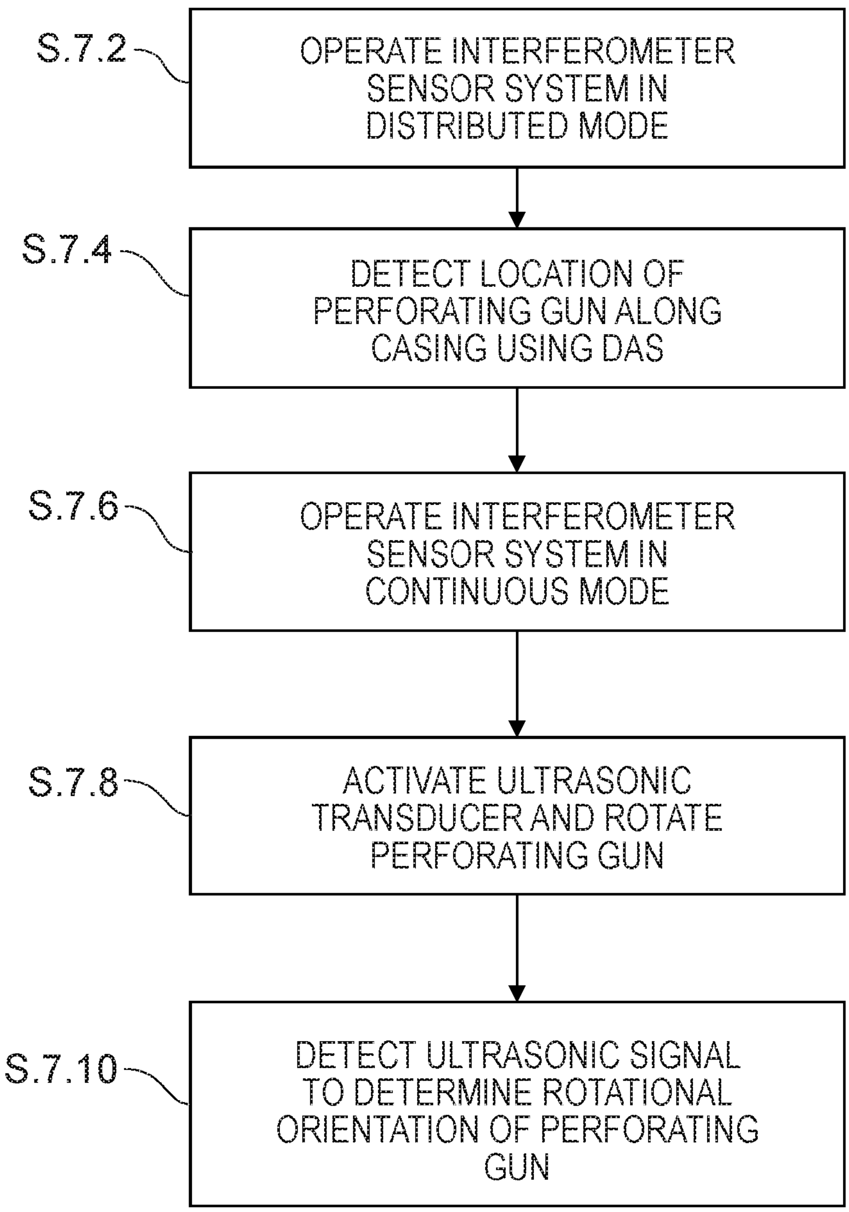
S.7.2
OPERATE INTERFEROMETER SENSOR SYSTEM IN DISTRIBUTED MODE
S.7.4
DETECT LOCATION OF PERFORATING GUN ALONG CASING USING DAS
S.7.6
OPERATE INTERFEROMETER SENSOR SYSTEM IN CONTINUOUS MODE
S.7.8
ACTIVATE ULTRASONIC TRANSDUCER AND ROTATE PERFORATING GUN
S.7.10
DETECT ULTRASONIC SIGNAL TO DETERMINE ROTATIONAL ORIENTATION OF PERFORATING GUN

FIG. 7

Method and System for Determining Downhole Object Orientation

Technical Field

The present invention provides a method and system for determining the orientation of a downhole object, and in particular for example an object such as a perforation gun used in the completion phase of an oil or gas well. Particular embodiments provide a method and system that ensure that the perforation gun will not damage any optical fibres installed in the well.

Background to the Invention and Prior Art

To detect an acoustic signal, distributed acoustic sensing (DAS) is commonly and effectively used. This method employs fibre optic cables to provide distributed acoustic sensing whereby the fibre optic cable acts as a string of discrete acoustic sensors, and an optoelectronic device measures and processes the returning signal. The operation of such a device is described next.

A pulse of light is sent into the optical fibre, and a small amount of light is naturally back scattered, along the length of the fibre by Rayleigh, Brilliouin and Raman scattering mechanisms. The scattered light is captured by the fibre and carried back towards the source where the returning signal is measured against time, allowing measurements in the amplitude, frequency and phase of the scattered light to be determined. If an acoustic wave is incident upon the cable, the glass structure of the optical fibre is caused to contract and expand within the vibro-acoustic field, consequently varying the optical path lengths between the back scattered light scattered from different locations along the fibre. This variation in path length is measured as a relative phase change, allowing the optical phase angle data to be used to measure the position of the acoustic signal at the point at which light is reflected. The returning signal can also be processed in order to determine the frequency of oscillation of vibration in the structure.

In known distributed acoustic sensing systems (DAS), standard fibre optic cables are utilised to obtain a measurement profile from along the entire length of the fibre at intervals ranging from 1-10 metres. Further details regarding the operation of a suitable DAS system, such as the iDAS™, available from Silixa Limited, of Elstree, UK are given in WO2010/0136809. Systems such as these are able to digitally record acoustic fields at every interval location along an optical fibre at frequencies up to 100kHz. Since the location of the acoustic sensors is known (the fibre deployment being known), the position of any acoustic signal can be thus identified by means of time-of-arrival calculations.

DAS systems find lots of applications in the oil and gas industry, and optical fibers that can be connected to DAS systems, amongst other things, are often installed within wellbores, usually running parallel with the well bore casing clamped to the outside thereof. In a typical oil or gas well, once the well bore has been drilled and the casing installed, cement is used to fill the well bore external of the casing. However, as part of the "completion" process of the well, the casing and cement is perforated within the hydrocarbon bearing regions, to allow hydrocarbons to flow into the casing for extraction. Perforation is typically performed by a perforating gun, which is typically a cylindrical metal tube provided with shaped explosive charges arranged around the circumference thereof. The perforating gun is lowered through the casing to the intended production zone, and the shaped charges are detonated, with the intention of blasting holes through the casing and cement of the well, and into the surrounding rock strata, to allow hydrocarbons to then flow through the created channels into the casing for extraction. Similarly, where a fracturing fluid is to be pumped into the well to fracture the rock strata, the created holes provide routes for the fracturing fluid to exit the well into the surrounding rock.

Figure 1 illustrates the use of a perforating gun to generate perforations in a well bore casing and cement, and into the surrounding rock strata. Perforating gun 10 comprises a metal cylinder provided with shaped explosive charges arranged around the outer surface thereof. For example, the shaped charges may be provided in lines every 120 degrees around the outer circumference of the gun. The gun is provided with a communications line 12 to the surface for control purposes, to allow the explosive charges to be detonated on command. In use as noted above the gun is lowered to the intended production zone, and the shaped charges detonated to blast through the casing and cement (as shown in Figure 1(b)), to create production channels in the surrounding rock strata through which oil or gas can flow to enter the well bore (as shown in Figure 1 (c)) .

One issue with the use of perforating guns is to try and prevent the shaped charges from damaging any control or sensing cabling or other lines that may extend along the wellbore external of the casing. For example, optical fibers are commonly installed along the external surface of the casing within the wellbore, either for sensing purposes and/or for control of downhole tools. Care must be taken when using a perforating gun that the shaped charges are not pointed at the external cabling or other lines such that the charges when detonated would sever such lines. As the perforating is performed as part of the well completion, by that point the fibers have typically already been cemented into the well bore, and hence repair can be very costly. To try and prevent such damage occurring, conventionally the fibers and other signalling lines are located between two metal rods, and a magnetometer is provided on the perforating gun to try and detect the metal rods. That is, the rotational orientation of the perforating gun is altered within the casing whilst the magnetometer is used to detect the location of the metal rods either side of the fibers or other cabling. Once the metal rods have been detected, the orientation of the perforating gun can be controlled to ensure that the shaped charges are pointed away from the area of the metal rods, and hence the cabling or other lines to be protected.

One problem with the above arrangement is one of cost, in that the metal rods are usually required to extend along a significant length of the well bore, hence increasing the material and production cost of the well. In addition, the use of magnetometers to detect the rods is not particularly accurate, and particularly in some rock formations or in some regions where magnetic anomalies can occur that interfere with the operation of the magnetometers. Morever, the presence of the casing and other downhole equipment can interfere with the proper operation of the magnetometers, meaning that it is not reliably possible to rotationally orient the perforating gun within the casing to ensure that the sensor and control lines and/or other cabling will not be damaged by the use of the perforating gun.

In order to address this problem WO2013/030555 describes a method and apparatus for determining the relative orientation of objects downhole, and especially to determining perforator orientation. The method, illustrated in Figure 2, involves varying the orientation of an object, such as a perforator gun (302) in the wellbore and activating at least one directional acoustic source (402a-c). Each directional acoustic source is fixed in a predetermined location to the object and transmits an acoustic signal preferentially in a known direction. The directional acoustic source(s) is/are activated so as to generate sound in a plurality of different orientations of said object. An optical fiber (104) deployed down the wellbore is interrogated to provide distributed acoustic sensing in the vicinity of the object and the acoustic signals detected by the optical fiber are analysed so as to determine the orientation of the at least one directional acoustic source relative to the optical fiber, for instance by looking at the relative intensity in the different orientations. Further details of the operation of the arrangement are described in the document, any and all of which necessary for understanding the present invention being incorporated herein by reference.

Therefore, whilst the arrangement in WO2013/030555 apparently should overcome the cost and inaccuracy of the prior art magnetometer arranngements, the arrangement relies on the operation of a DAS system to detect the directional acoustic sources, with the directional acoustic sources being described as conventional loudspeakers arranged to project sounds forward and located in a casing that absorbs sound emitted in other directions. Conventional loudspeakers typically operate within audible frequency bands, for example in the range 20 Hz to 20KHz, and a typical DAS of the prior art is usually capable of detecting sound at these frequencies with good spatial resolution. However, the directionality of conventional loudspeakers, even provided in an otherwise insulating casing, is not high, and -3dB directivity arcs of +/- 50 to 60º can be common. Figure 2 has been annotated to show typical example -directivity arcs for the three loudspeakers. As shown, such directivity often means that even if the speaker is pointed away from the optical fibre, the fiber may still pick up a large signal from the speaker. Allowing further for echoes and other multi-path effects within the casing, and the reliability of such a system begins to deteriorate. Basically, using conventional speakers as described in the prior art does not give a high enough directivity for the sound emitted to reliably determine the orientation of the perforating gun.

Summary of the Invention

Embodiments of the present invention improve upon the arrangement described in WO2013/030555 by using higher frequency, ultrasonic transducers that are significantly more directional than conventional loudspeakers. Ultrasonic transducers, such as piezo or ferroelectric transducers, are known in the art that generate highly directional soundwaves with frequencies from 100 KHz up to many (50) MHz. As directionality of a sound transducer is proportional to the frequencies emitted therefrom, with higher frequencies typically being more directional, using an ultrasonic transducer results in a significantly more directional output than with conventional loudspeakers. Hence, if the fiber detects the highly directional soundwave, then it becomes possible to be more certain of the orientaion of the object to which the transducer is affixed, knowing the relative arrangement between the transducer and the object.

One problem with using such high frequency ultrasonic sources, however, is that a conventional distributed acoustic sensor system can typically only detect sound up to about 100 kHz, and hence will be unable to detect such ultrasound sources. However, in some embodiments of the present invention this problem is solved by operating the DAS equipment in a non-distributed mode, and in particular by operating the laser in the DAS equipment in a continuous wave (cw) mode, such that cw light propagates along the fiber throughout sensing. The fiber is still sensitive to incident ultrasonic vibrations, and the usual backscatter effects (e.g. Rayleigh, Brillouin and Raman) upon which DAS systems rely still occur, but because of the continuous wave operation the sensing equipment is unable to resolve the location of the incident sound along the sensing fiber (there are no pulses being sent along the fiber, the backscatter from which can be timed to determine location). However, the sensing equipment in the DAS is still able to detect that such backscatter effects occur, and hence that there is incident ultrasonic energy incident on the fiber somewhere. From this detection it can then be inferred, absent other sources of incident ultrasonic energy on the fiber, that the ultrasonic source on the perforating gun must be pointing at the fiber, and hence the relative rotational orientation of the fiber and the ultrasonic transducer (and hence the perforating gun) can also be inferred with more accuracy than in the case of the prior art.

The above described operation therefore implies a two stage operation for use of the DAS system in aiding in location and orientation of the perforating gun. Firstly, the DAS system may be operated in normal distrubuted mode, where sensing pulses are sent down the fiber in a conventional manner, to monitor the deployment of the perforating gun down the casing into the desired production zone. Then, once the position of the perforating gun along the casing has been determined, the DAS system is put into a non-distributed mode of operation, where a continuous signal is sent down the fiber, and backscatter therefrom processed. As noted above, the use of a continous signal prevents the system processor from resolving spatial location along the fiber, but provided there are no other ultrasonic sources this is not an issue. However, the continuous wave fiber sensor is able to determine that there is an ultrasonic source incident on the fiber. The rotational orientation of the perforating gun is then altered (essentially the gun is rotated within the casing), whilst the ultrasonic source operates, or the rotational orientation is altered and then the source is operated at the new orientaion. When the fiber sensor detects the ultrasonic source it means that the source, which is highly directional, must be pointing at the fiber, and hence the rotational orientation of the perforating gun, to which the source is affixed in known relation, can be accurately determined. Having determined the rotational orientation of the perforating gun within the casing, the rotational orientation can then be controlled so that none of the shaped charges in the gun point towards the fiber, or other cabling on the outside of the casing.

In view of the above from one aspect the present invention provides a method for determing the orientation of a downhole object, comprising: providing the downhole object with a high frequency highly directional sound source fixed in known relation to the object; operating the high frequency directional sound source; rotating the downhole object; and detecting the high frequency directional sound source using an optical fiber acoustic sensing system deployed downhole when the high frequency directional sound source is pointing at the optical fiber; wherein the rotational orientation of the downhole object with respect to the optical fiber is determined based on the detection of the sound source and the known fixed relation between the sound source and the object.

In one embodiment the high frequency directional sound source is an ultrasonic transducer. The ultrasonic transducer may be arranged to operate at frequencies in excess of 50 kHz, or in excess of 100 kHz, or in excess of 200 kHz.

Particularly, in some embodiments the optical fiber sensing system is arranged to operate in a continuous wave mode so as to be able to detect the high frequency sound incident on the optical fiber. In some embodiments this lead to a two stage operation. First the optical fiber acoustic sensing system is operated as a convention distributed acoustic sensor (DAS) system to locate the object downhole, and then operation switches to a second mode, where the optical fiber acoustic sensing system operates in a continuous wave mode to determine the rotational orientaion of the object at the located position.

Further features and aspects of the invention will be apparent from the appended claims.

Brief description of Drawings

Embodiments of the present invention, presented by way of example only, will now be described, with reference to the accompanying drawings, wherein like reference numerals refer to like parts, and wherein:

Figure 1 is a drawing illustrating the prior art operation of a perforating gun;

Figure 2 is a drawing from the prior art illustrating the wide-field effects of loud speakers of the prior art;

Figure 3 is a drawing of a perforating gun of an embodiment of the present invention, provided with at least one ultrasonic source thereon;

Figure 4 is a drawing of a perforating gun of an embodiment of the present invention illustrating the narrow-field effects of the use of an ultrasonic source;

Figure 5 is a diagram illustrating a typical deployment scenario for embodiments of the present invention;

Figure 6 is a graph illustrating the detection output of the continuous wave interferometer sensor system, with respect to rotational angle of the perforating gun; and

Figure 7 is a flow diagram illustrating the typical steps employed in an embodiment of the invention.

Detailed description of preferred embodiments

In an embodiment of the invention a perforating gun 32 is provided. The perforating gun 32 comprises a generally cylindrical object having sections provided therein in which shaped explosive charges 38 can be mounted. Suitable detonators (not shown) and control electronics (not shown) are also included, controlled via control line 34. In use, as known in the art, the perforating gun is lowered into the casing of a wellbore during the completion phase, and moved into the intended production zone. The shaped charges are then fired to blow holes through the casing and cement into the surrounding rock strata.

In order to allow the rotational orientation of the perforating gun to be determine when the gun is deployed within the wellbore casing, an ultrasonic transducer 36, such as piezo or ferroelectric transducer, is provided. The transducer operates at any ultrasonic frequency, although preferably from 100kHz to 50 MHz, with the directionality of the ultrasonic signal being dependent on the frequency and the transducer design. The precise design of the ultrasonic transducer is beyond the scope of the present application, suffice to say that many highly directional ultrasonic transducer designs are known in the art suitable for use in the present embodiment.

Ultrasonic transducers can be obtained, for example, from Olympus NDT Corporation, of Waltham, Massachusets, USA, or from components suppliers such as Premier Farnell, or RS. For example, the PROWAVE 235AC130 TRANSMITTER, ULTRASONIC, 235KHZ, 13MM, available from Premier Farnell UK Limited, of Leeds, UK, provides a -6dB beamwidth of only 15 degrees at 235kHz.

Within Figure 3 a single ultrasonic transducer is shown. However, in other embodiments multiple ultrasonic transducers may be included, for example arranged around the circumference of the perforating gun as shown in Figure 4. Here the arrangement is such that the transducers 36 are equiangularly arranged around the circumference. In addition or alternatively, plural (e.g. two or more) ultrasonic transducers may be located at the same rotational position on the perforating gun (not shown in Figure 4). Where plural transducers are provided arranged around the circumference of the gun, then the transducers may operate on the same frequency, provided the beamwidths are narrow enough so as not to significantly overlap. For example, provided the -6dB beamwidths of rotationally adjacent transducers do not overlap, then there should be sufficient separation. In Figure 4, the dotted lines illustrate example soundfields from the transducers. As shown, the sound beamwidths are very narrow, thus providing greater accuracy in determining the rotational orientation of the gun.

However, in other more preferable embodiments, the transducers 36 arranged at different positions around the circumference of the gun operate on different frequencies. Providing different known frequencies from transducers at known relative positions can help the acoustic sensing system resolve the rotational orientation of the perforating gun within the casing more accurately.

Where there are plural (two or more) transducers located side by side at the same angular position on the circumference of the gun then these transducers should operate at different frequencies. In such a case the different frequencies would be picked up by the fiber optic acoustic sensor simultaneously, when the plural transducers are commonly directed at the fiber. The different frequencies can act as both an identification and rotational position signature for the perforating gun, and provide a measure of anti-jamming performance, for example in the presence of an inadvertent interfering signal. For example, the side-by-side transducers may operate at two known ultrasonic frequencies, which may be widely separated in the spectrum, for example by 50 kHz or more. In use the fiber optic acoustic sensor would pick up both signals simultaneously, at the same rotational position of the gun. If the rotational position that provides the maximum value for both signals is found, then it is highly likely that the gun is in a position where the transducers are pointing directly at the fiber, and the incident ultrasound on the fiber is as a result of a direct path from the transducers to the fiber, rather than having suffered any reflections or multi-path propagation between the transducers and the fiber. In such a case, the ability of the arrangement to accurately determine the rotational position of gun with respect to the fiber is increased.

Figure 5 illustrates a typical deployment scenario for embodiments of the present invention. Here, a wellbore 52 has been drilled, and casing 54 installed therein, cement surrounding the casing to secure the casing within the wellbore 52. The casing is provided running along its outer surface with one or more optical fibers 56 or other cabling, for signalling, sensing or control purposes. The cabling 56 including the optical fiber is secured to the casing 54 via clamps 57, located typically every few meters along the casing. During completion of the wellbore perforating gun 32 is inserted into the casing 54, and moved along the casing 32 to the intended production zone of the well. An optical interferometric sensing system 58, such as a distributed acoustic sensing (DAS) system is provided, connected to optical fiber 56, which may operate in a distributed acoustic sensing mode as known in the art to monitor the insertion of the perforating gun 32 into and along the casing 54. The DAS system may be a

Silixa™ iDAS™ system, the details of operation of which are available at the URL http://www.silixa.com/technology/idas/, and which is also described in our earlier patent application WO2010/0136809, any details of which that are necessary for understanding the present invention being incorporated herein by reference.

In the present embodiment the sensing system 58 may operate in a distributed acoustic sensing mode to monitor the insertion of the perforating gun 32 into the casing 54, and to determine the position of the gun 32 along the casing. However, the sensing system 58 may then be switched to operate in a continuous wave mode, which is used to determine the rotational orientation of the gun within the casing. In the continuous wave mode, the laser of the sensing system is operated in a continuous wave mode to continually send laser light along the fiber during the sensing periods. The fiber is affected by incident ultrasonic sound waves from the ultrasonic transducers in the same manner as known in the art i.e. Rayleigh, Brillouin, and Raman backscatter occur, dependent on the incident sound energy, but due to the continuous wave propagating in the fiber rather than pulses, any timing information, which is indicative of location along the fiber is lost. Therefore, the continuous wave backscatter from the incident ultrasonic wave can be detected and resolved by the interferometer detector unit in the interferometric sensing system 58 to detect the ultrasonic incident sound energy on the fiber, but not to locate it along the fiber – it is simply possible to tell that such ultrasonic sound energy is incident on the fiber somewhere along its length.

The advantage of the continuous wave operation, however, is that because there is no need to take into account pulse timing of pulses propagating along the fiber in the detector to determine location, the detector is able to detect much higher frequency sound incident on the fiber than is the case than when operating in distributed (DAS) mode, and in particular should be able to detect incident ultrasound across the ultrasound frequency band. Hence, in the present embodiment, with the sensor system 58 operating in continuous mode, any ultrsound being emitted by source 36 on the perforating gun will be detected by the sensor system 58 as the arc of emitted ultrasound sweeps over the fiber as the perforating gun is caused to rotate in the casing. Figure 6 illustrates an example output plot of the amplitude of sound at ultrasound frequency ω (which may be in the range e.g. 100 kHz to 50 MHz) with respect to rotational angle θ of the perforating gun 32 within the casing 54, as detected by sensor system 58 operating in continuous wave mode. As will be seen, as the gun 32 rotates within the casing the output amplitude $A(\omega)$ at frequency ω remains substantially constant at a background level, until the source 36 is pointing at the fiber at rotational position θ_1. At that rotational position the ultrasonic soure 36 is pointing directly at the fiber, and this manifests itself as a spike in the detected sound on the fiber at frequency ω of the ultrasonic source. Hence, at that point the operator knows that ultrasonic source 36 is pointing directly at the fiber, and by then knowing the position of the source 36 on the perforating gun 32, the rotational orientation of the perforating gun is thus found.

Figure 7 is a flow diagram illustrating the sequence of operations in the present embodiment, given the equipment described above. In particular, at s.7.2 the interferometer sensor system is first operated in conventional distributed acoustic sensing mode, whilst the perforating gun 32 is inserted into the casing. In this way the DAS can the track the location of the perforating gun at step 7.4, as the gun is moved along the casing into the desired production zone of the well that is to be perforated.

Once the location of the gun within the well casing has been determined, and the gun located where required, the interferometer sensing system 58 is then switched into continuous wave mode operation, at s.7.6. As described above, this prevents the sensoor form determining position of incident sound along the fibre, but allows the sensor to detect incident sound of much higher frequency that is incident anywhere along the fiber. With the sensing system 58 operating in this mode, the one or more ultrasonic transducers 36 provided on the perforating gun 34 are turned on, and caused to emit a highly directional ultrasound beam. The perforating gun is then rotated in the casing, such that the ultrasound beam sweeps around as the gun rotates (s.7.8). When the gun is rotated such that ultrasound source is pointing at the fiber 56 the ultrasound beam sweeps over the fiber, thus causing backscatter effects in the fiber, which are detected by the interferometric sensor system 58, thus manifesting themselves as a peak in the sensor output, as described. When the peak is detected the operator then knows that at the point the perforating gun is oriented such that the ultrasound source is pointing at the fiber, and hence given a priori knowledge of the location and orientation of the source on the gun, the rotational orientation of the gun within the casing is found.

In one preferred embodiment, the acoustic source 36 is located so that its beam is not located on the same radial axis as the axes of fire of any of the shaped charges 38. In such an embodiment, when the acoustic source beam is pointing at the fiber, and the high frequency sound therefrom is being detected as incident on the fiber, the operator thus knows that at that point none of the shaped charges are pointing at the fiber, and hence it is safe to fire the charges.

Various modifications to the above described embodiment may be made, whether by way of addition, deletion, or substitution, to provide further embodiments, any and all of which are intended to be encompassed by the appended claims.

Claims

1. A method for determing the orientation of a downhole object, comprising:

providing the downhole object with a high frequency highly directional sound source fixed in known relation to the object;

operating the high frequency directional sound source;

rotating the downhole object; and

detecting the high frequency directional sound source using an optical fiber acoustic sensing system deployed downhole when the high frequency directional sound source is pointing at the optical fiber;

wherein the rotational orientation of the downhole object with respect to the optical fiber is determined based on the detection of the sound source and the known fixed relation between the sound source and the object.

2. A method according to claim 1, wherein the high frequency directional sound source is an ultrasonic transducer.

3. A method according to claim 2, wherein the ultrasonic transducer is arranged to operate at frequencies in excess of 50 kHz.

4. A method according to claims 2 or 3 wherein the ultrasonic transducer is arranged to operate at frequencies in excess of 100 kHz.

5. A method according to any of claims 2 to 4 wherein the ultrasonic transducer is arranged to operate at frequencies in excess of 200 kHz.

6. A method according to any of the preceding claims, wherein the optical fiber sensing system is arranged to operate in a continuous wave mode so as to be able to detect high frequency sound incident on the optical fiber.

7. A method according to any of the preceding claims, wherein the object is provided with a plurality of high frequency directional sound sources in known positions on the object.

8. A method according to claim 7, wherein the plurality of sound sources are circumferentially distributed around the exterior of the object.

9. A method according to claim 7 or 8, wherein at least two of the plurality of sound sources are co-located at the same rotational angular position on the object.

10. A method according to any of the preceding claims, wherein two or more of the plurality of sound sources operate at different high frequencies.

11. A method according to claim 11, wherein the operating frequencies are ultrasonic frequencies.

12. A method according to claim 12, wherein the ultrasonic frequencies are in excess of 100 kHz.

13. A method according to any of the preceding claims, wherein the optical fiber acoustic sensing system operates as a distributed acoustic sensor system during the insertion of the object downhole in order to be able to determine the location of the object downhole.

14. A method according to any of the preceding claims, wherein the object is a perforating gun arranged to be be deployed within casing installed within a wellbore, the wellbore having the optical fiber extending over at least part of the length thereof.

15. A method according to claim 14, wherein the perforating gun comprises one or more shaped charges radially directionally oriented around the perforating gun, the high frequency directional sound source being located in known directional orientation with respect to the shaped charges.

16. A method according to claim 15, wherein the one or more shaped charges are radially directionally oriented in one or more different radial directions than the at least one high frequency directional sound source.

17. An optical fiber acoustic sensing system, comprising:

an optical fiber deployed downhole;

an optical interferometer arranged to detect optical backscatter signals from the optical fiber caused by a high frequency directional sound source incident on the optical fiber and to convert said backscatter signals to electrical signals; and

a processor arranged to process said electrical signals to detect the high frequency directional sound source incident on the optical fiber, and to indicate said detection;

wherein the rotational orientation of a downhole object with respect to the optical fiber is determined based on the detection of the sound source and a known fixed relation between the sound source and the object.

18. A system according to claim 17, wherein the high frequency directional sound source is an ultrasonic transducer.

19. A system according to claim 18, wherein the ultrasonic transducer is arranged to operate at frequencies in excess of 50 kHz.

20. A system according to claims17 or 18 wherein the ultrasonic transducer is arranged to operate at frequencies in excess of 100 kHz.

21. A system according to any of claims 18 to 20 wherein the ultrasonic transducer is arranged to operate at frequencies in excess of 200 kHz.

22. A system according to any of claims 17 to 21, wherein the optical fiber acoustic sensing system is arranged to operate in a continuous wave mode so as to be able to detect high frequency sound incident on the optical fiber.

23. A system according to any of claims 17 to 22, wherein the optical fiber acoustic sensing system operates as a distributed acoustic sensor system during the insertion of the object downhole in order to be able to determine the location of the object downhole.

24. A downhole object having a high frequency highly directional sound source fixed in known relation thereto.

25. An object according to claim 24, wherein the sound source is an ultrasonic transducer.

26. An object according to claim 25, wherein the ultrasonic transducer is arranged to operate at frequencies in excess of 50 kHz.

27. An object according to claims 25 or 26 wherein the ultrasonic transducer is arranged to operate at frequencies in excess of 100 kHz.

28. An object according to any of claims 25 to 27 wherein the ultrasonic transducer is arranged to operate at frequencies in excess of 200 kHz.

29. An object according to any of claims 24 to 28, wherein the object is a perforating gun arranged to be be deployed within casing installed within a wellbore, the wellbore having the optical fiber extending over at least part of the length thereof.

30. An object according to claim 29, wherein the perforating gun comprises one or more shaped charges radially directionally oriented around the perforating gun, the high frequency directional sound source being located in known directional orientation with respect to the shaped charges.

31. An object according to claim 30, wherein the one or more shaped charges are radially directionally oriented in one or more different radial directions than the at least one high frequency directional sound source.

Application No:	GB1401671.1	**Examiner:**	Mr Richard Oseland
Claims searched:	1-31	**Date of search:**	30 April 2015

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1, 7, 8, 9, 10, 14, 15, 17, 24, 29, 30	WO2013/030555 A2 (OPTASENSE HOLDINGS LTD) see figures 3a-4 especially, description and claims, especially claims 1-8 & 25-28 disclosing a high frequency directional sound source 402a, fixed in known relation to the object 302, detecting the sound source using an optical fiber acoustic sensing system.
X	1, 7, 8, 9, 10, 14, 15, 17, 24, 29, 30	US2013/329522 A1 (HALLIBURTON ENERGY SERV INC) see figures 1-4, description, especially paragraphs [0013]-[0021] & [0061] and claims disclosing a high frequency directional sound source 32, fixed in known relation to the object, detecting the sound source using an optical fiber acoustic sensing system 34.
A	-	WO2012/084997 A2 (SHELL INT RESEARCH)
A	-	WO2012/068558 A1 (REDFEN INTEGRATED OPTICS INC)
A	-	GB2491658 A (SILIXA LTD)
A	-	US2013/021615 A1 (BAKER HUGHES INC)

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

E21B; G01D; G01H

The following online and other databases have been used in the preparation of this search report

EPODOC, WPI, TXTE

International Classification:

Subclass	Subgroup	Valid From
E21B	0047/024	01/01/2006
E21B	0043/116	01/01/2006
E21B	0043/119	01/01/2006
E21B	0047/022	01/01/2012
E21B	0047/09	01/01/2012
E21B	0047/14	01/01/2006
G01V	0001/44	01/01/2006