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(54) Title: LOCATION OF DOWNHOLE LINES

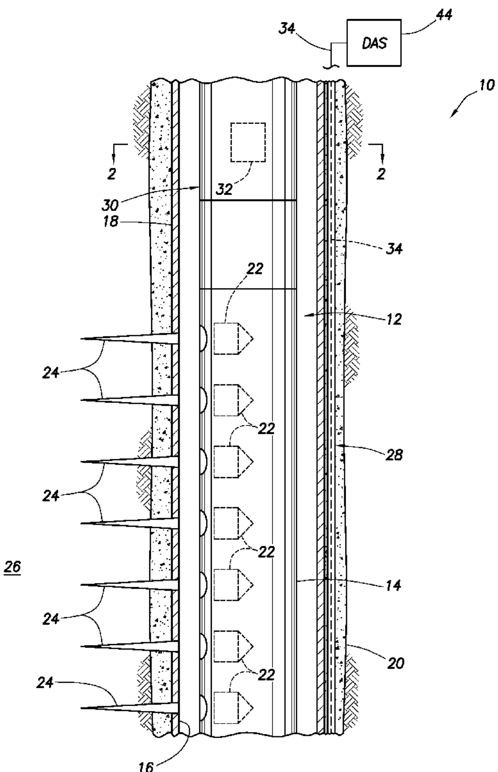

FIG. 1

(57) Abstract: A method of determining an azimuthal orientation of a well tool relative to a line in a well can include connecting at least one acoustic source to the well tool, the acoustic source having a known azimuthal orientation relative to the well tool, and detecting at least one acoustic signal transmitted from the acoustic source to an acoustic sensor, the acoustic sensor having a known azimuthal orientation relative to the line. A system for determining an azimuthal orientation of one or more lines relative to a well tool in a wellbore can include at least one acoustic source having a known azimuthal orientation relative to the well tool, and an optical waveguide connected to a distributed acoustic sensing instrumentation, the waveguide having a known azimuthal orientation relative to the lines, and in which the distributed acoustic sensing instrumentation detects acoustic signals transmitted from the acoustic source to the waveguide.

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LOCATION OF DOWNHOLE LINES

TECHNICAL FIELD

This disclosure relates generally to equipment utilized and operations performed in conjunction with a subterranean well and, in an example described below, more particularly provides for location of downhole lines.

BACKGROUND

In some advanced, intelligent or SMARTWELL(TM) completions, lines (such as, fiber optic or other cables, electrical lines, hydraulic lines, etc.) may be cemented in a well external to casing. After cementing, the casing and cement are typically perforated, in order to provide for flow between an interior of the casing and an earth formation surrounding the casing.

It will be appreciated that it would be beneficial to be able to prevent damage to the lines (for example, in perforating operations) by being able to accurately locate the lines relative to the casing downhole.

SUMMARY

In the disclosure below, systems and methods are provided which bring improvements to the art of locating lines downhole. One example is described below in which an optical waveguide is positioned external to the casing (such as, adjacent to, or as one of, the lines) and an acoustic source is deployed in the casing. Another example is described below in which distributed acoustic sensing is used to locate the position of an acoustic source relative to an optical waveguide external to, or otherwise positioned relative to, the casing.

A method of determining an azimuthal orientation of a well tool relative to a line in a well is described below. In one example, the method can include connecting at least one acoustic source to the well tool, the acoustic source having a known azimuthal orientation relative to the well tool; and detecting at least one acoustic signal transmitted from the acoustic source to an optical waveguide, the waveguide having a known azimuthal orientation relative to the line.

Also described below is a system for determining an azimuthal orientation of one or more lines relative to a well tool in a wellbore. The system, in one example, includes at least one acoustic source having a known azimuthal orientation relative to the well tool, and an optical waveguide connected to a distributed acoustic sensing instrumentation. The waveguide has a known azimuthal orientation relative to the lines, and the distributed acoustic sensing instrumentation detects acoustic signals transmitted from the acoustic source to the waveguide.

These and other features, advantages and benefits will become apparent to one of ordinary skill in the art upon

careful consideration of the detailed description of representative examples below and the accompanying drawings, in which similar elements are indicated in the various figures using the same reference numbers.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a representative partially cross-sectional view of a well system and associated method which can embody principles of this disclosure.

FIG. 2 is a representative cross-sectional view of the system, taken along line 2-2 of FIG. 1.

FIG. 3 is a representative elevational view of an acoustic source and a distributed acoustic sensor of the system.

FIG. 4 is a representative cross-sectional view of the system, in which multiple acoustic sources are utilized.

DETAILED DESCRIPTION

Representatively illustrated in FIG. 1 is a system 10 for use with a subterranean well, and an associated method, which can embody principles of this disclosure. However, it should be clearly understood that the system 10 and method are merely one example of an application of the principles of this disclosure in practice, and a wide variety of other examples are possible. Therefore, the scope of this disclosure is not limited at all to the details of the system 10 and method described herein and/or depicted in the drawings.

In the FIG. 1 example, a well tool 12 is deployed into a wellbore 16 lined with casing 18 and cement 20. The well tool 12 in this example includes a perforating gun 14 with explosive shaped charges 22 for forming perforations 24 through the casing 18 and cement 20, and into an earth formation 26 penetrated by the wellbore.

The perforations 24 provide for fluid communication between the wellbore 16 and the formation 26. Such fluid communication might be used for producing fluid from the formation 26, for injecting fluid into the formation, or for any other purpose.

The term "casing" is used herein to indicate a protective wellbore lining. Casing can include specific tubulars known to those skilled in the art as "casing," "liner" or "tubing." Casing can be made of any material(s), including metals, composites, plastics, etc. Casing can be segmented or continuous. Casing can be pre-formed, or formed *in situ*.

The term "cement" is used herein to indicate a flowable material which hardens after being flowed into position in a well. Cement is typically used to seal off an annular area between a casing and a formation wall or another tubular. Cement can be made of a cementitious material, although other materials (such as resins, composites, foams, plastics, etc.) may be used.

At this point it should be noted that it is not necessary in keeping with the scope of this disclosure for the well tool 12 to include the perforating gun 14, or for perforations 24 to be formed through casing 18 or cement 20. In other examples, the well tool 12 could include other types of equipment, such as jetting tools, lateral tie-back tools, or any other types of tools. Equipment which can particularly benefit from the principles described herein include those for which it would be desirable to be able to accurately measure azimuthal orientation (that is, rotational orientation about a longitudinal axis) relative to one or more lines 28 positioned external to the casing 18.

In the FIG. 1 example, it is desired to know the azimuthal orientation of the charges 22 relative to the lines 28, so that the perforations 24 are not formed through the lines, thereby damaging the lines. Instead, it would be preferable for the perforations 24 to be formed in a direction away from the lines 28. In other examples, it may be desired to pierce the lines 28.

If the azimuthal orientation of the well tool 12 relative to the lines 28 can be accurately measured, then proper positioning of the well tool 12 can be confirmed. Or, if the azimuthal orientation of the well tool 12 is improper, then the orientation can be corrected (e.g., by rotating the well tool in the wellbore 16), using the relative orientation measurement as a basis for the correction.

For measuring the relative azimuthal orientation of the well tool 12 relative to the lines 28, an acoustic transmitter 30 is connected to the well tool. The transmitter 30 includes an acoustic source 32 which has a known azimuthal orientation relative to the well tool 12 (or a particular feature of the well tool, such as the perforating charges 22, a jetting nozzle, etc.). For example, when the transmitter 30 is assembled to the perforating gun 14 prior to being deployed into the wellbore 16, the azimuthal orientation of the acoustic source 32 relative to the charges 22 could be measured and/or fixed.

Acoustic signals transmitted by the transmitter 30 are sensed by an optical waveguide 34 (such as an optical fiber, an optical ribbon, etc.). The waveguide 34 may be one of the lines 28, the waveguide may be positioned adjacent the lines, or otherwise in a known azimuthal orientation relative to the lines.

Preferably, the optical waveguide 34 is one of the lines 28. The optical waveguide 34 may be part of a cable, or installed in a tube (such as a control line), before or after the tube is installed in the well. For example, the waveguide 34 could be pumped into a tube 36 (see FIG. 2) after the tube is cemented in the well external to the casing 18.

The optical waveguide 34 is only one example of an acoustic sensor which can detect acoustic signals transmitted by the well tool 12. In other examples, other types of acoustic sensors (e.g., a piezoelectric receiver, an accelerometer, a strain sensor, etc.) may be used. Such sensors could be connected to lines other than optical waveguides (e.g., electrical lines, etc.).

Note that it is not necessary for the lines 28 to be positioned external to the casing 18. In other examples, the lines 28 (including the waveguide 34) could be in a sidewall of the casing 18. In further examples, the lines 28 could be internal to the casing 18. Thus, it should be clearly understood that the scope of this disclosure is not limited at all to the details of the system 10 as depicted in the drawings and described herein.

It is not necessary for the acoustic transmitter 30 to be rigidly connected to the perforating gun 14 or any other type of well tool. Instead, the acoustic transmitter 30 could be separately conveyed into the well and engaged with the perforating gun 14 (or other well tool), for example, using an orienting profile, so that the engaged transmitter has a known azimuthal orientation relative to the well tool.

In other examples, the orienting profile in the well could have a known azimuthal orientation relative to the lines 28. For example, the orienting profile could be interconnected in the casing 18. After engagement with the orienting profile, an azimuthal orientation of the separately conveyed acoustic transmitter 30 could be measured, for example, using a magnetometer, gravitometer or integrated gyroscope. The acoustic transmitter 30 would then be withdrawn from the well, and perforating charges in a gravity-oriented perforating gun could be selectively positioned to miss (or hit) the lines.

Referring additionally now to FIG. 2, a cross-sectional view of the system 10 is representatively illustrated, taken along line 2-2 of FIG. 1 (that is, through the acoustic transmitter 30). In this view, it may be more clearly seen how the azimuthal orientation of the acoustic source 32 can relate to the azimuthal orientation of the lines 28 (including the waveguide 34) with respect to a longitudinal axis 38 of the well tool 12.

The waveguide 34 serves as a sensor to detect acoustic signals transmitted by the acoustic source 32. Preferably, the waveguide 34 is part of a distributed acoustic sensing (DAS) system. For example, DAS instrumentation 44 can be connected to the waveguide 34 at the earth's surface, a subsea location, etc., and used to detect acoustic vibrations at any location along the waveguide.

Suitable DAS systems for use with the waveguide 34 are described in U.S. Publication Nos. 2011-0088462 and 2012-0014211. These prior publications are incorporated herein by this reference for all purposes.

The DAS instrumentation 44 effectively converts a length of single mode optical waveguide 34 into a distributed acoustic sensor, capable of detecting acoustic noise or sound waves continually along the waveguide's length. The waveguide 34 may be installed with the lines 28, or installed thereafter (e.g., pumped into an empty tube 36 after cementing the casing 18 and empty tube in the well).

The waveguide 34 may be used only for detecting the azimuthal orientation of the well tool 12, or it may be used for other purposes (for example, distributed temperature sensing (DTS), pressure sensing, data and/or command telemetry, etc.). If not used after detecting the azimuthal orientation of the well tool 12, the waveguide 34 may be removed, or it may be left in place.

The acoustic source 32 is depicted in FIG. 2 as being azimuthally oriented at an angle θ relative to the waveguide 34. When the acoustic source 32 emits an acoustic signal (such as, a bang, tap, impulse, sound, chirp, etc.), an acoustic pulse propagates away from the source.

The acoustic pulse travels around the circumference of the casing 18 from the acoustic source 32 to the waveguide 34, along Paths A & B illustrated in FIG. 2, assuming that the longitudinal positions of the acoustic source and the detection location along the waveguide are the same (e.g., location 40 shown in FIG. 3). Note that Path A is shorter than Path B.

As a result, two initial acoustic pulses will be detected by the waveguide 34 at location 40. These acoustic pulses will be separated in time as given by the following equation (1):

$$dt = D * (\pi - \theta)/V \qquad (1)$$

in which V is the speed of sound in the casing 18 material, and D is the diameter of the casing.

Note that there is no separation in time (only one pulse is detected) when $\theta = \pi$, since the source 32 would be pointing directly away from the waveguide 34, and the two Paths A & B would have the same length.

Similarly, if $\theta = 0$, only one pulse is detected. In this case, the two Paths A & B are the same, and they have no or minimal length. In order to differentiate between these two relative azimuthal orientations ($\theta = \pi$ and $\theta = 0$), the time at which the acoustic source 32 emits the acoustic signal should be known. The travel time to the waveguide 34 will be much shorter if $\theta = 0$, as compared to if $\theta = \pi$.

If two pulses are detected, the acoustic source 34 is oriented at an angle θ other than 0 or π relative to the waveguide 34. The angle θ is given by the following equation (2):

$$+/- \theta = \pi - (dt * V/D) \qquad (2)$$

Thus, by detecting a difference in time of acoustic pulses arriving at the waveguide 34, the azimuthal orientation of the acoustic source 32 (and the well tool 12 connected thereto) relative to the waveguide (and the lines 28) can be readily determined. In this manner, for example, the charges 22 can be confirmed as pointing away from the lines 28 or, if the charges are found to be pointing toward the lines, the well tool 12 can be rotated until the charges do not point toward the lines.

If acoustic damping in the system 10 is relatively low, one could (and likely would) detect multiple pulses, with diminishing amplitudes as acoustic waves make multiple passes about the circumference of the casing 18. These secondary pulses likely would rapidly distort, and one would likely start to see reflections from casing collars or other discontinuities, which would diminish the usefulness of all but the first received pulse or pulses in determining the orientation of the source 32 relative to the waveguide 34.

In this description, a detected "one pulse" or "two pulses" refers to the initial detected pulses which travel via direct routes from the source 32 to the waveguide 34, for example, without traveling completely around the casing 18, and without reflecting off of ends of the casing or other discontinuities, etc.

It is worth noting that the acoustic pulses from the source 32 will be detected all along the waveguide 34, and not just at the location 40 which is in the plane of the source, and at a same longitudinal position. As depicted in FIG. 3, the acoustic pulses will also be detected at another location 42 along the waveguide 34, with the location 42 being separated by a longitudinal distance *Z* from the location 40. It is conceived that detection of the acoustic signals at the location 42, as well as at the location 40, can be useful at least in confirming measurements made at the location 40, and possibly in providing enhanced spatial indications.

Although specific locations 40, 42 are mentioned above, it is understood that the waveguide 34, when connected to the DAS instrumentation 44, provides for detection of acoustic signals all along the waveguide. Specific detection locations 40, 42 along the waveguide 34 may be used for convenience when analyzing the detected acoustic signals.

In another example, frequency domain techniques may be used, instead of or in addition to the time domain techniques discussed above. In one example, the acoustic source 32 could emit an acoustic signal continuously, with the acoustic signal having a characteristic frequency and wavelength, as given by equation (3):

$$\lambda = \frac{v}{f}, \qquad (3)$$

where λ is the wavelength, f is the frequency, and v is the speed of sound in the casing 18 material. Neglecting attenuation, an acoustic wave will propagate with distance l from the source 32 according to the solution to the wave equation given by equation (4):

$$A(l) = A_0 \cos\left(\frac{2\pi}{\lambda} l\right), \qquad (4)$$

where $A(l)$ is the amplitude at distance l, and A_0 is the amplitude at the source 32. At location 42 depicted in FIG. 3, separated by distance Z from the source 32, an approximation of the total amplitude of the received wave is given by equation (5):

$$A(z) = A_0 \sum_{n=1}^{\infty} \cos\left(\frac{2\pi}{\lambda} l_n\right) \qquad (5)$$

where $A(z)$ is the amplitude at the location 42, and l_n are the different path lengths between the source 32 and the location 42. The total acoustic power in the received wave (that signal which is detected at the source 32) is proportional to $I(z)$ as given by equation (6):

$$I(z) = \left(A(z)\right)^2 = \left[A_0 \sum_{n=1}^{\infty} \cos\left(\frac{2\pi}{\lambda} l_n\right)\right]^2. \qquad (6)$$

The result is that, along the waveguide 34, acoustic energy will form an interference pattern which will depend on the variables *D, θ, v, f and Z*. With proper analysis of this interference pattern, the azimuthal orientation of the source 32 relative to the waveguide 34 can be readily determined. Thus, digital signal processing techniques known to those skilled in the art can be used to relate the interference patterns to the azimuthal orientation of the source 32 relative to the waveguide 34.

Therefore, it will be appreciated that the acoustic signals transmitted by the acoustic transmitter 30 could be continuous with a constant frequency, multiple different constant frequencies could be transmitted, and/or acoustic pulses could be transmitted. Various techniques known to those skilled in the art may be used to relate the transmitted acoustic signals (with constant or varying, and the same or different, frequencies, amplitudes, etc.) to the azimuthal orientation of the acoustic transmitter 30.

Referring additionally now to FIG. 4, another example of the system 10 is representatively illustrated. In this example, the acoustic transmitter 30 includes multiple acoustic sources 32a-h.

Each acoustic source 32a-h could be associated with a particular well tool 12 or feature of a well tool. For example, each acoustic source 32a-h could be associated with a particular perforating gun 14, or a particular perforating charge 22 of a gun.

When the sources 32a-h emit acoustic signals, the time of travel from each of the sources to the waveguide 34 will be different, if the distances between the sources and the waveguide are different. For example, in the configuration depicted in FIG. 4, an acoustic signal transmitted from the source 32a will arrive at the waveguide 34 in less time than an acoustic signal transmitted from the source 32d will arrive at the waveguide.

Acoustic signals could be transmitted from the sources 32a-h in sequence and, by measuring the differences in travel times, the azimuthal orientation of the transmitter 30 relative to the waveguide 34 can be readily determined. For example, if it is determined that the acoustic source 32a is closest to the waveguide 34 (as depicted in FIG. 4), and the perforating charges 22 are aligned with any of the acoustic sources 32c-32g, it may be considered that it is acceptable to fire the charges to form the perforations 24.

If the charges 22 are aligned with either of the sources 32b or h, then it is less likely that it would be considered prudent to fire the charges, if damage to the lines 28 is to be avoided. If the charges are aligned with source 32a, then the charges would not be fired until after the perforating gun 14 is repositioned (unless, of course, the objective is to pierce the lines 28).

It is expected that the amplitudes of the pulses received from the different sources 32a-h at the waveguide 34 will also be different. The largest amplitude would be received from the source 32a, and the least amplitude would be received from the source 32e, in the situation depicted in FIG. 4. Comparison of the pulse amplitudes, thus, provides another way to determine the azimuthal orientation of the transmitter 30 relative to the waveguide 34.

Multiple sources 32a-h may be used to transmit acoustic signals at multiple different azimuthal orientations. Alternatively, a single acoustic source 32 could be rotated relative to the well tool 12, with the source transmitting acoustic signals at different azimuthal orientations. In this example, the well tool 12 could rotate with the acoustic source, if desired.

The acoustic sources 32, 32a-h described above can be relatively simple electrical, mechanical, fluid-operated or otherwise actuated devices. For example, a spring-loaded metal striker activated by a pulsed electromagnetic solenoid could be a suitable acoustic source. A piezoelectric or electrostrictive material may be used to produce an acoustic pulse. Fluid could be ejected from, or received into, the well tool 12, thereby creating acoustic "noise." A laser could be pulsed to generate vibrations in the casing 18. An acoustic signal could be generated by scraping on the casing 18. Any manner of producing the acoustic signal may be used, in keeping with the scope of this disclosure.

One beneficial aspect of the system 10 (in any of the examples of FIGS. 1-4) is that no radioactive materials are used to indicate the azimuthal orientation of the lines 28. The method described above should also provide reliable and accurate determination of the azimuthal orientation of the well tool 12 relative to the lines 28.

There is no need to modify current techniques of installing lines external to casing, or in a casing sidewall. The DAS instrumentation 44 may only be used during the determination of the azimuthal orientation of the well tool 12, after which the DAS instrumentation can be used at other locations (although the DAS instrumentation could also be used for long-term monitoring of the well, e.g., as described in the above-incorporated application disclosures).

Lines 28 can be installed internal or external to the casing 18, or in a sidewall of the casing, without concern that perforations 24 will later pierce the lines, or that other types of well tools will damage the lines. The waveguide 34 can be installed with the lines 28, or later when a need arises to determine the azimuthal orientation of the well tool 12 relative to the lines.

A method of determining an azimuthal orientation of a well tool 12 relative to a line 28 in a well is described above. In one example, the method can comprise: connecting at least one acoustic source 32 to the well tool 12, the acoustic source 32 having a known azimuthal orientation relative to the well tool 12; and detecting at least one acoustic signal transmitted from the acoustic source 32 to an optical waveguide 34 or other type of acoustic sensor, the acoustic sensor having a known azimuthal orientation relative to the line 28.

The line 28 may comprise the waveguide 34, whereby the waveguide 34 has the same azimuthal orientation as the line 28. The line 28 can be positioned external to a casing 18, in a sidewall or the casing, inside the casing, or in any other position. The waveguide 34 can be positioned external to a casing 18, or in any other position.

The well tool 12 in one example comprises a perforating gun 14. The method can include determining an azimuthal orientation of the perforating gun 14 relative to the line 28, based on the acoustic signal detecting step.

The method can include determining the azimuthal orientation of the well tool 12 relative to the line 28, based on a difference in time between multiple acoustic signals being detected, and/or based on a difference in interference patterns between multiple detected acoustic signals.

Multiple acoustic sources 32a-h can be connected to the well tool 12, with each acoustic source having a different azimuthal orientation relative to the well tool 12. The acoustic source 32 may transmit the acoustic signal at multiple different azimuthal orientations relative to the well tool 12.

Distributed acoustic signals can be detected along the waveguide 34. The acoustic signal can be detected at multiple longitudinally spaced apart locations 40, 42 along the waveguide 34.

Also described above is a system 10 for determining an azimuthal orientation of one or more lines 28 relative to a well tool 12 in a wellbore 16. In one example, the system 10 can include at least one acoustic source 32 having a known azimuthal orientation relative to the well tool 12, and an optical waveguide 34 connected to a distributed acoustic sensing instrumentation 44, the waveguide 34 having a known azimuthal orientation relative to the lines 28. The distributed acoustic sensing instrumentation 44 detects acoustic signals transmitted from the acoustic source 32 to the waveguide 34.

Although various examples have been described above, with each example having certain features, it should be understood that it is not necessary for a particular feature of one example to be used exclusively with that example. Instead, any of the features described above and/or depicted in the drawings can be combined with any of the examples, in addition to or in substitution for any of the other features of those examples. One example's features are not mutually exclusive to another example's features. Instead, the scope of this disclosure encompasses any combination of any of the features.

Although each example described above includes a certain combination of features, it should be understood that it is not necessary for all features of an example to be used. Instead, any of the features described above can be used, without any other particular feature or features also being used.

It should be understood that the various embodiments described herein may be utilized in various orientations, such as inclined, inverted, horizontal, vertical, etc., and in various configurations, without departing from the principles of this disclosure. The embodiments are described merely as examples of useful applications of the principles of the disclosure, which is not limited to any specific details of these embodiments.

In the above description of the representative examples, directional terms (such as “above,” “below,” “upper,” “lower,” etc.) are used for convenience in referring to the accompanying drawings. However, it should be clearly understood that the scope of this disclosure is not limited to any particular directions described herein.

The terms “including,” “includes,” “comprising,” “comprises,” and similar terms are used in a non-limiting sense in this specification. For example, if a system, method, apparatus, device, etc., is described as “including” a certain feature or element, the system, method, apparatus, device, etc., can include that feature or element, and can also include other features or elements. Similarly, the term “comprises” is considered to mean “comprises, but is not limited to.”

Of course, a person skilled in the art would, upon a careful consideration of the above description of representative embodiments of the disclosure, readily appreciate that many modifications, additions, substitutions, deletions, and other changes may be made to the specific embodiments, and such changes are contemplated by the principles of this disclosure. For example, structures disclosed as being separately formed can, in other examples, be integrally formed and *vice versa*. Accordingly, the foregoing detailed description is to be clearly understood as being given by way of illustration and example only, the spirit and scope of the invention being limited solely by the appended claims and their equivalents.

WHAT IS CLAIMED IS:

1. A method of determining an azimuthal orientation of a well tool relative to a line in a well, the method comprising:

connecting at least one acoustic source to the well tool, the acoustic source having a known azimuthal orientation relative to the well tool; and

detecting at least one acoustic signal transmitted from the acoustic source to an acoustic sensor, the sensor having a known azimuthal orientation relative to the line.

2. The method of claim 1, wherein the acoustic sensor comprises an optical waveguide.

3. The method of claim 2, wherein the line comprises the waveguide, whereby the waveguide has the same azimuthal orientation as the line.

4. The method of claim 2, wherein the waveguide is positioned external to a casing.

5. The method of claim 2, wherein distributed acoustic signals are detected along the waveguide.

6. The method of claim 2, wherein the acoustic signal is detected at multiple longitudinally spaced apart locations along the waveguide.

7. The method of claim 1, wherein the line is positioned external to a casing.

8. The method of claim 1, wherein the well tool comprises a perforating gun, and further comprising determining an azimuthal orientation of the perforating gun relative to the line, based on the acoustic signal detecting.

9. The method of claim 1, further comprising determining the azimuthal orientation of the well tool relative to the line, based on a difference in time between multiple acoustic signals being detected.

10. The method of claim 1, further comprising determining the azimuthal orientation of the well tool relative to the line, based on a difference in interference patterns between multiple detected acoustic signals.

11. The method of claim 1, further comprising determining the azimuthal orientation of the well tool relative to the line, based on a difference in amplitude between multiple detected acoustic signals.

12. The method of claim 1, wherein multiple acoustic sources are connected to the well tool, each acoustic source having a different azimuthal orientation relative to the well tool.

13. The method of claim 1, wherein the acoustic source transmits the acoustic signal at multiple different azimuthal orientations relative to the well tool.

14. The method of claim 1, wherein the acoustic signal is transmitted continuously with a substantially constant frequency.

15. The method of claim 1, wherein the acoustic signal comprises multiple signals with different frequencies.

16. The method of claim 1, wherein the acoustic signal comprises acoustic pulses.

17. A system for determining an azimuthal orientation of one or more lines relative to a well tool in a wellbore, the system comprising:

at least one acoustic source having a known azimuthal orientation relative to the well tool; and

an optical waveguide connected to a distributed acoustic sensing instrumentation, the waveguide having a known azimuthal orientation relative to the lines, and

wherein the distributed acoustic sensing instrumentation detects acoustic signals transmitted from the acoustic source to the waveguide.

18. The system of claim 17, wherein the lines comprise the waveguide, whereby the waveguide has the same azimuthal orientation as the lines.

19. The system of claim 17, wherein the lines are positioned external to a casing.

20. The system of claim 17, wherein the waveguide is positioned external to a casing.

21. The system of claim 17, wherein the well tool comprises a perforating gun.

22. The system of claim 17, wherein the azimuthal orientation of the well tool relative to the line is

determined, based on a difference in time between multiple acoustic signals being detected.

23. The system of claim 17, wherein the azimuthal orientation of the well tool relative to the line is determined, based on a difference in interference patterns between multiple detected acoustic signals.

24. The system of claim 17, wherein the azimuthal orientation of the well tool relative to the line is determined, based on a difference in amplitude between multiple detected acoustic signals.

25. The system of claim 17, wherein multiple acoustic sources are connected to the well tool, each acoustic source having a different azimuthal orientation relative to the well tool.

26. The system of claim 17, wherein the acoustic source transmits the acoustic signal at multiple different azimuthal orientations relative to the well tool.

27. The system of claim 17, wherein the acoustic signal is transmitted continuously with a substantially constant frequency.

28. The system of claim 17, wherein the acoustic signal comprises multiple signals with different frequencies.

29. The system of claim 17, wherein the acoustic signal comprises acoustic pulses.

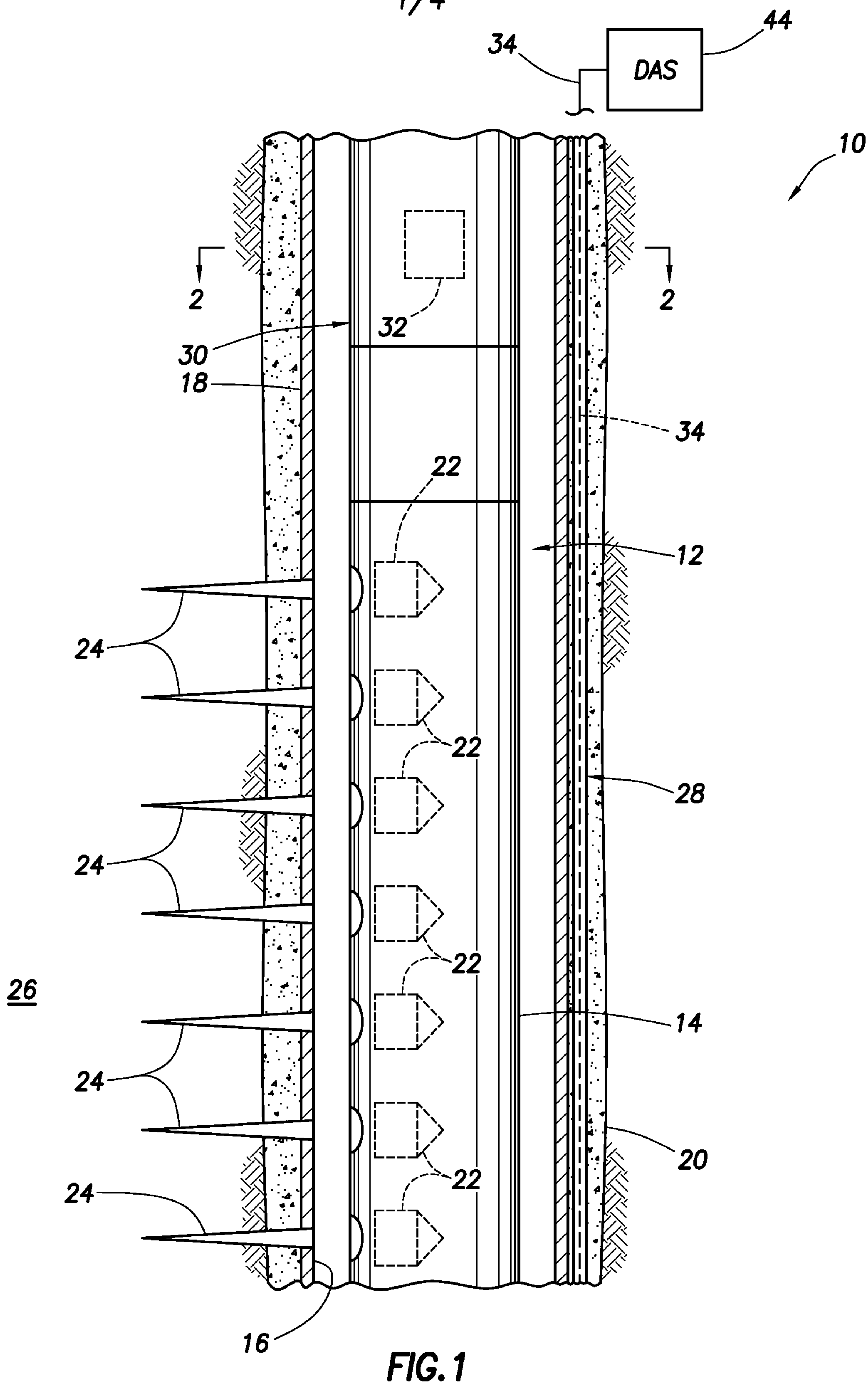

FIG.1

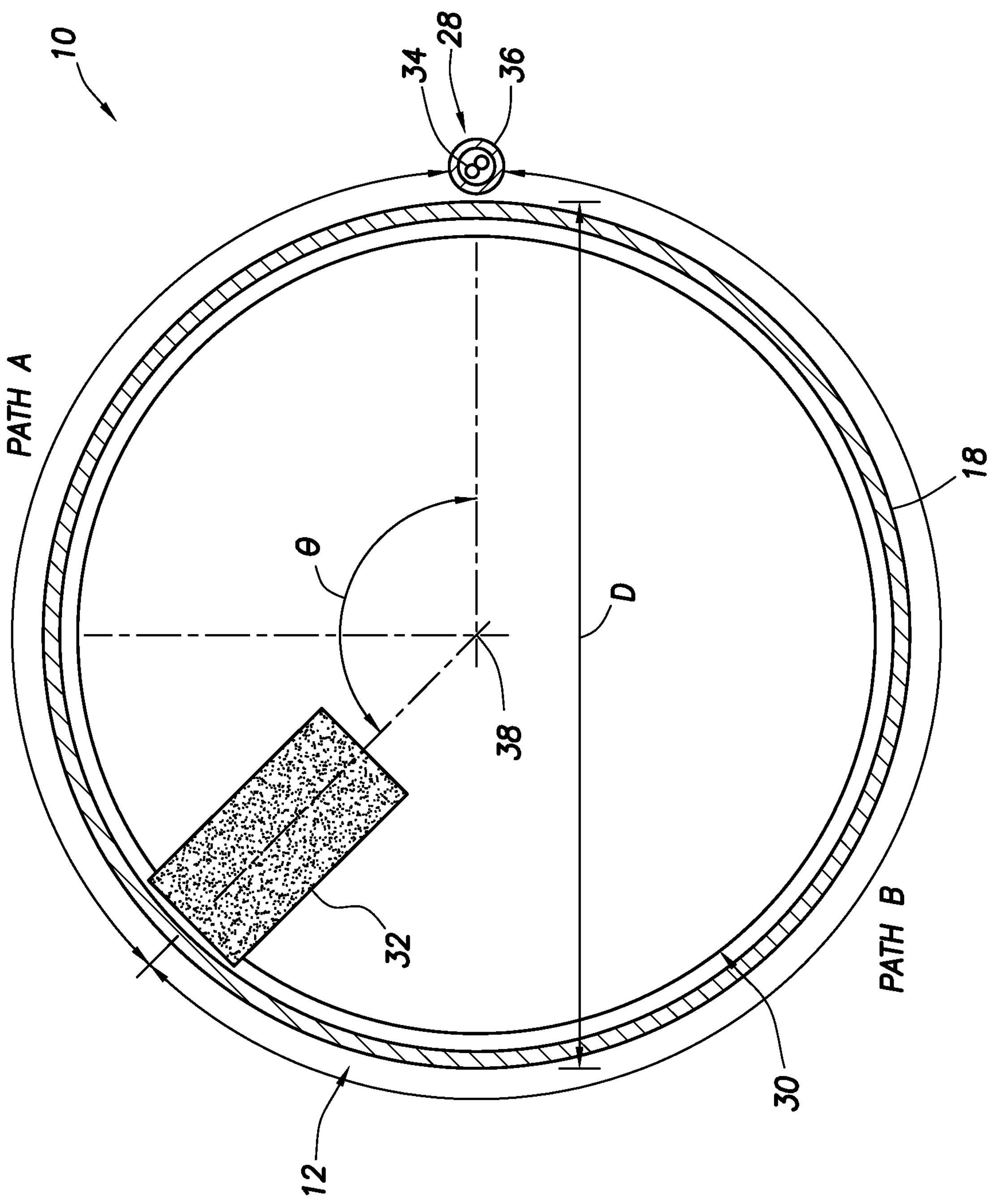

FIG.2

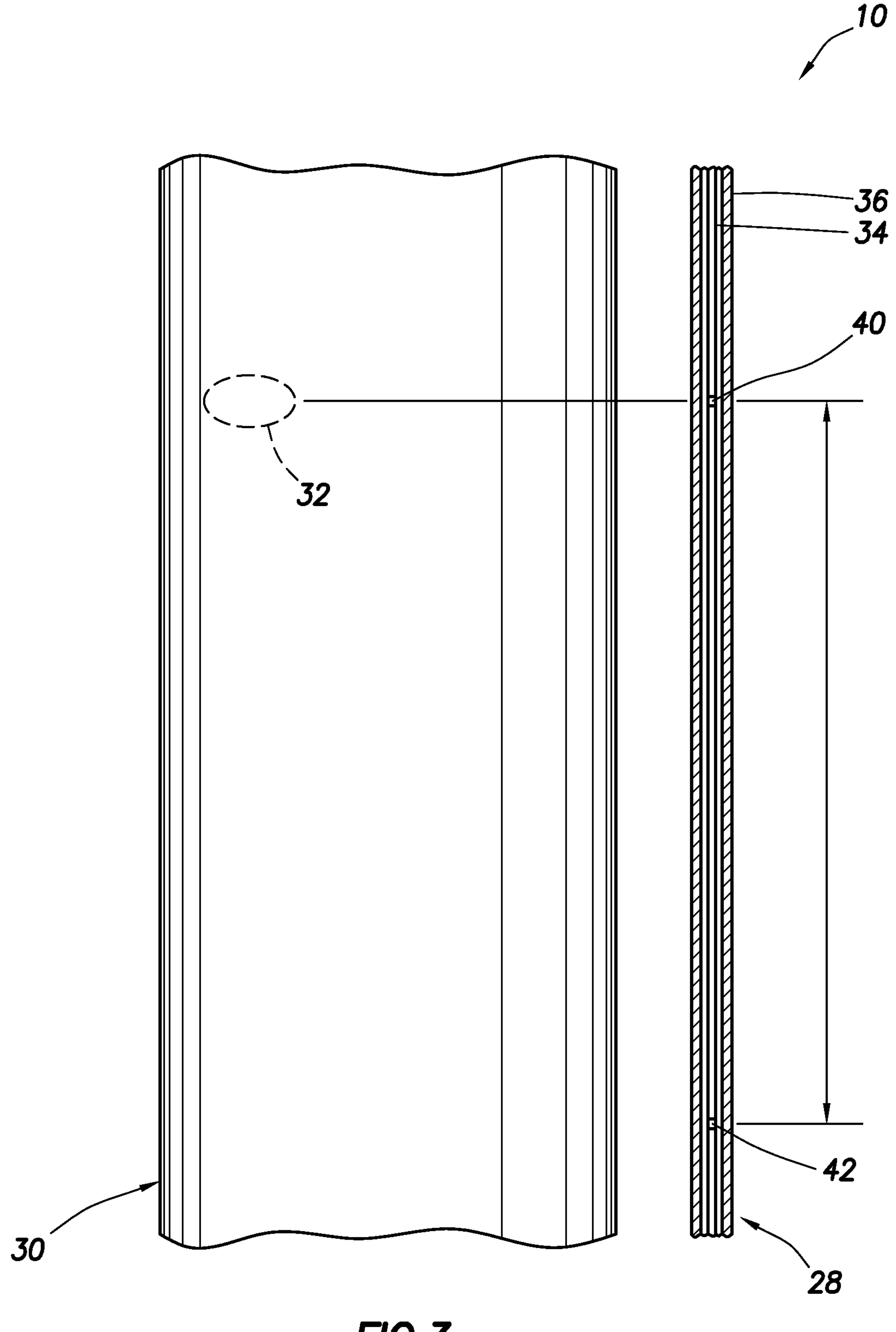

FIG.3

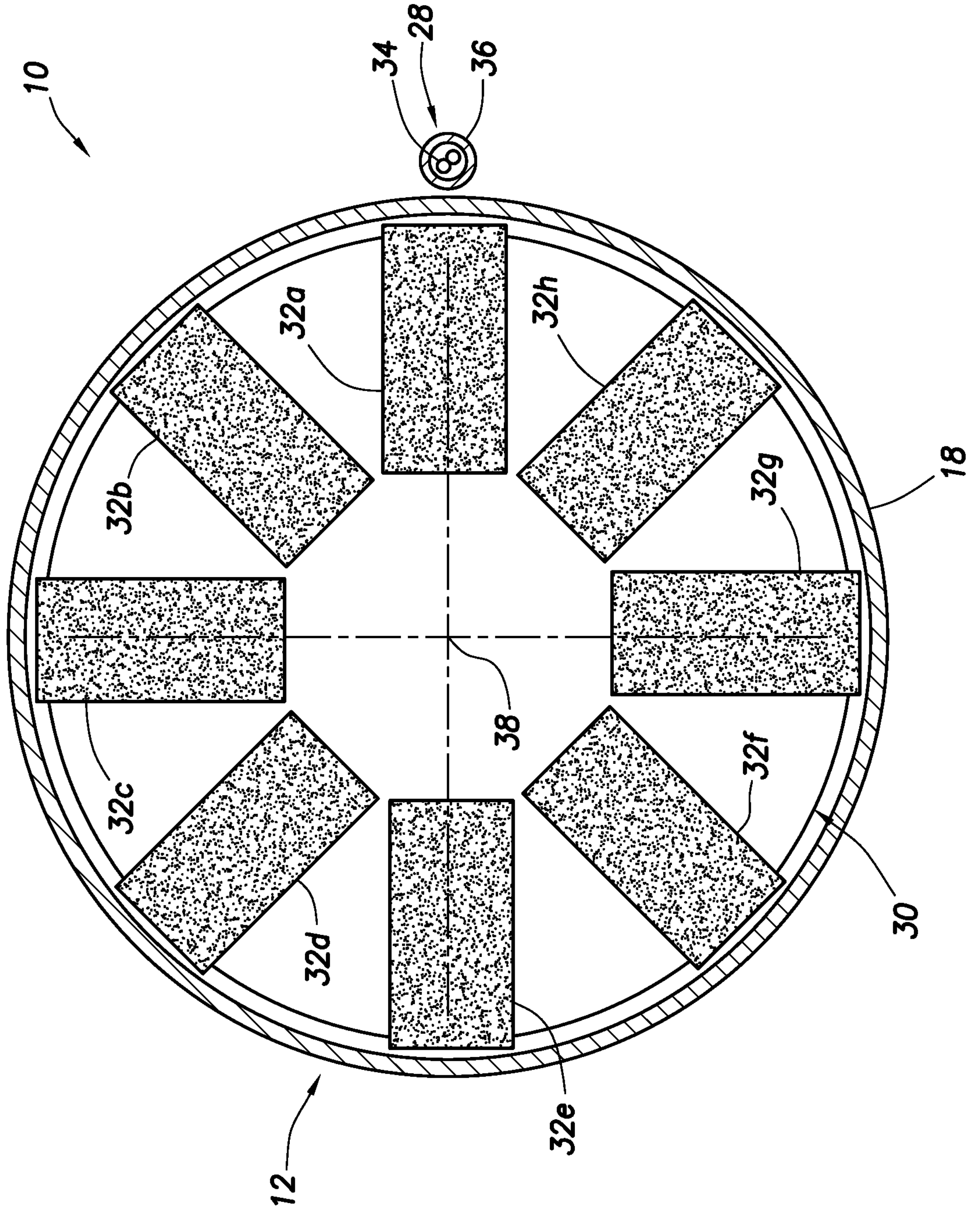

FIG.4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/044034

A. CLASSIFICATION OF SUBJECT MATTER

E21B 47/095(2012.01)i, E21B 47/14(2006.01)i

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)
E21B 47/095; E21B 47/00; E21B 49/00; E21B 43/118; E21B 43/26; G01V 1/40; G01V 1/00; E21B 47/14

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords:perforating, azimuthal orientation, acoustic signal, sensor, and waveguide

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2008-0264639 A1 (PARROTT et al.) 30 October 2008 See paragraphs [0106]-[0110] and figure 33.	1,7-8,13
Y		2-6,9-12,14-29
Y	US 2011-0308788 A1 (RAVI et al.) 22 December 2011 See abstract; paragraphs [0023]-[0030]; and figures 1,3.	2-6,12,14-29
Y	US 2012-0111560 A1 (HILL et al.) 10 May 2012 See abstract and paragraph [0041].	9,22
Y	US 4641724 A (CHOW et al.) 10 February 1987 See abstract; column 5, lines 35-40; and figures 1,5,9.	10-11,23-24
A	US 2008-0170466 A1 (MICKAEL, MEDHAT W.) 17 July 2008 See paragraphs [0010]-[0012] and claims 1,14.	1-29

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
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"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"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
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"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	Date of mailing of the international search report
22 August 2013 (22.08.2013)	**23 August 2013 (23.08.2013)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

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