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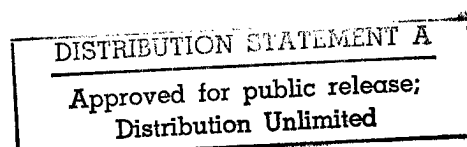
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1 N. C. 75828

2 IMPROVED SUBMARINE DEPLOYED SEA-STATE SENSOR

3
4 STATEMENT OF GOVERNMENT INTEREST

5 The invention described herein may be manufactured by or for
6 the Government of the United States of America for Governmental
7 purposes without the payment of any royalties thereon or
8 therefor.

9
10 BACKGROUND OF THE INVENTION

11 (1) Field of the Invention

12 The invention relates generally to the field of electronic
13 sensing devices, and more particularly to sensors for sensing
14 selected conditions on an ocean surface. The invention
15 specifically provides a sensor which may be deployed by a
16 submarine or other submerged platform, which can obtain wave
17 statistics regarding significant wave height, mean and "rms"
18 (root-mean-square) wave height, wave frequency spectra
19 information, variance, the significance and mean period and sea
20 state, from which conditions such as surface wind speed can be
21 determined.

22 (2) Description of the Prior Art

23 It is often necessary for a platform such as a submarine
24 submerged in, for example, an ocean environment, to determine
25 wave conditions at the surface. Wave conditions can, for
26 example, adversely effect launch of a missile. High-energy wave

1 conditions can produce dynamic motions and pressure fluctuations
2 which can perturb or damage slowly ascending missiles. Large
3 waves can cause rolling motions which are transferred to the
4 submarine, which can prevent safe launching of any missile
5 system. In addition, whitecap turbulence of breaking waves can
6 scatter and absorb sound energy used by sonar devices and the
7 like which are used by torpedoes after launching.

8 U. S. Patent No. 4,694,575 describes a submarine-launched
9 sea state buoy which can be deployed by a submerged platform for
10 use in sensing surface conditions, such as wave amplitude and
11 frequency. The buoy described in that patent includes a multi-
12 chambered, buoyant cylindrical housing which houses an
13 accelerometer and other electronic equipment. The buoy floats on
14 the ocean surface and the accelerometer senses vertical
15 acceleration of the buoy by the surface wave motion. The buoy
16 includes a counterweight that operates to maintain the buoy in a
17 predetermined orientation on the surface. A wire data link links
18 the accelerometer and electronic equipment on the buoy to the
19 submerged platform to provide data generated by the accelerometer
20 and electronic equipment to the submerged platform. A
21 predetermined time after deployment, the buoy will be scuttled by
22 flooding.

23 There are a number of problems with the buoy as described in
24 the '575 patent. For example, when the buoy is fully deployed,
25 the data link can abrade on the edge of the buoy housing, which
26 can interrupt data transmission. In addition, the buoy's motion

1 damping means does not provide sufficient extension of mass of
2 the body to sufficiently reduce pitch and roll. Further,
3 scuttling of the buoy will prevent its re-use.

4 In copending U.S. Patent Application Ser. No. 08/591,183,
5 filed 5 April 1996 in the name of David Shonting, entitled
6 Submarine Deployed Sea State Sensor (Navy Case No. 75829)
7 assigned to the assignee of the present invention there is a
8 description of a sea state sensor that solves a number of the
9 problems inherent in the buoy described in the '575 patent.
10 However, that sensor has a relatively large number of parts, and
11 can be expensive to assemble.

12 13 SUMMARY OF THE INVENTION

14 It is therefore an object of the invention to provide a new
15 and improved submarine-deployed sea state sensor.

16 In brief summary, a submarine deployed sea-state sensor
17 comprising an elongated housing having a nose cone and an aft
18 end, the housing having a forward buoyant chamber for receiving
19 an accelerometer. The housing has, aft of the buoyant chamber, a
20 damping assembly including a motion damping body, communication
21 link deployment means and a lifting body, with both the damping
22 assembly and the lifting body being attached to a communication
23 link interconnecting the accelerometer and a submerged platform
24 so that, when the portion of the communication link between the
25 lifting body and the submerged platform becomes taught, the
26 lifting body is pulled from the housing. The damping assembly

1 and lifting body are releasably joined so that, when the lifting
2 body is pulled from the housing, the lifting body pulls the
3 damping assembly toward the aft end of the housing into a
4 position in which at least a majority of the longitudinal expanse
5 of the motion damping body is distended from the aft end of the
6 housing.

7 8 BRIEF DESCRIPTION OF THE DRAWINGS

9 This invention is pointed out with particularity in the
10 appended claims. The above and further advantages of this
11 invention may be better understood by referring to the following
12 description taken in conjunction with the accompanying drawings,
13 in which:

14 FIG. 1 is a mechanical schematic of a submarine deployed
15 spar buoy-type sea state sensor constructed in accordance with
16 the invention, it being understood that the depicted spar buoy
17 configuration has an exaggerated diameter-to-longitudinal-length
18 envelope;

19 FIG. 2 is another mechanical schematic representing the
20 sensor of FIG. 1, but in a state of its operation in which a
21 motion damping assembly depends from the original longitudinal
22 envelope of the sensor, and a lifting body assembly is separated
23 from the spar buoy;

24 FIG. 3 is an enlarged detail representing a structural
25 embodiment of the motion damping assembly located in the
26 midsection of the sensor of FIG. 1, and which more particularly

1 is in part a cutaway view depicting the side elevation of a first
2 tier of internal components exposed, in part a cutaway view
3 depicting the side elevation of a second more inwardly disposed
4 tier of components, and in part a central section;

5 FIG. 3A is a section taken along lines 3A-3A, FIG. 3; and

6 FIG. 4 is a functional block diagram depicting apparatus for
7 processing signals received from the sea state sensor depicted in
8 FIGs. 1 and 2.

9
10 DESCRIPTION OF THE PREFERRED EMBODIMENT

11 FIG. 1 is a diagram, in schematic form, of a submarine
12 deployed sea state sensor 10 constructed in accordance with the
13 invention. With reference to FIG. 1, sensor 10 is effectively in
14 the form of a spar buoy comprising a cylindrical housing 11
15 including a cylindrical sidewall 12 with a removable
16 hemispherical nose cone 13. A restriction 18 is formed at the
17 aft end 23 of the housing 11. The housing 11 houses a sealed
18 electronics package 14 that includes conventional accelerometer
19 and preliminary processing circuitry (not separately shown) that
20 can detect acceleration as applied to the accelerometer and
21 generate an output signal representative thereof for transmission
22 to a deploying platform such as a submarine. The housing 11 also
23 houses three other subsystems, namely, a damping assembly 15, a
24 lifting body assembly 16, and a communication link dispensing
25 assembly 17, the latter comprising a pair of helical coil and
26 spool units 17a, 17b. Coil and spool units 17a, 17b respectively

1 axially pay out communication link line upon increase of distance
2 of separation of assemblies 15 and 16. Unit 17a is attached to
3 assembly 15 and unit 17b is attached to assembly 16.

4 Generally, electronics package 14 is mounted in a sealed
5 waterproof chamber 20 formed by the removable nose cone 13, a
6 bulkhead 21 and a portion of the sidewall 12 between the nose
7 cone 13 and the bulkhead. The nose cone 13 is removable so that,
8 prior to deployment of the sensor 10, an operator can remove the
9 nose cone, and activate the electronics package 14 by means of,
10 for example, a switch 22. After activation, the operator can
11 restore the nose cone to re-seal the chamber 20. In one
12 embodiment, the nose cone 13 is threadably mounted on the
13 sidewall 12 to form the chamber 20.

14 Once sensor 10 is launched, the portion thereof below
15 bulkhead 21 becomes flooded with seawater through the aft open
16 end of sidewall 12. To this end, the components of damping
17 assembly 15 and of lifting body assembly are so constructed and
18 arranged that, upon the sensor 10 being deployed in the ocean
19 environment, quick flooding of the interior of sensor 10 up to
20 bulkhead 21 occurs through the open aft end of housing 12.
21 During storage prior to employment a removable cap (not shown)
22 may be used to cover the aft end 23 of the housing 11.

23 As noted above, the housing 11 houses, in addition to the
24 electronics package 14, three other subsystems, namely, a damping
25 assembly 15, a lifting body assembly 16, and a communication link
26 dispensing assembly 17. The damping assembly 15, after

1 deployment, will help dampen pitch and roll of the sensor 10,
2 that is, deviations of the sensor 10 from the vertical, and in
3 addition can dampen motion due to high-frequency wave motion, so
4 that the sensor 10 will primarily sense low-frequency motion
5 reflecting to conditions that can affect missile launch.

6 The damping assembly includes a cylindrical tube 30. A
7 fixed spacer ring 31 is mounted to the interior bore of sidewall
8 12, in confronting relationship to tube 30. Suitable annular
9 passages and perforations in transverse members, are provided to
10 enable water to quickly move from the aft end of the sidewall and
11 flood the interior of the sidewall up to bulkhead 21. Openings
12 30a, FIG. 3, are provided in tube 10 to enable its interior to
13 quickly flood. A slip ring 32 is mounted around the tube 30 below
14 the fixed spacer ring 31. A strap 33 affixes the tube 30 to the
15 underside of the bulkhead 21. Referring to FIGS. 2 and 3, the
16 midpoint of strap 33 is affixed to bulkhead 21 and its ends are
17 fixedly bound to the outer periphery of tube 30 at a
18 predetermined linear position between the ends of the tube, with
19 the strap ends positioned at diametrically opposite positions
20 about the tube. The strap ends are bound in these positions by
21 means of a strip of plastic 30b which circumscribes and is
22 cemented to tube 30. Coil and spool unit 17a is mounted within
23 the lower end of the tube 30 via a support structure consisting
24 of a transverse plate 34 which slidably translates along the
25 bore of tube 30, and is stopped from exiting the tube by collar
26 30c.

1 The sea state sensor device described in the above-
2 identified copending Application, Serial No. 08/591,183 includes
3 a distending motion damping assembly comprising a three section
4 telescoping members of a hard metal material such as stainless
5 steel. In contrast, in accordance with the present invention the
6 damping body is fabrication from a tube of substantially lighter
7 weight material such as lucite. Therefore the center of buoyancy
8 is higher reducing the response to high frequency waves (i.e.,
9 splashes).

10 The lifting body assembly 16 assists in deployment of both
11 the damping assembly and the communication link 24 which connects
12 the electronics package 14 to the deploying submarine (not
13 shown). The lifting body assembly 16 includes a cylindrical body
14 35. Coil and spool unit 17b is mounted on the upper end of the
15 cylindrical body 35. The communication link 24 is coupled
16 bulkhead 21 via an insulation connector 40, FIG. 3 extends
17 longitudinally through tube 30, is wound around units 17a and
18 17b, and is also wound around the cylindrical body 35. A pair of
19 central pintles 19a, 19b are parts, respectively, of
20 communication link coil and spool units 17a and 17b, and project
21 from the aft and forward ends of these respective units. The
22 pintles are so constructed and arranged to promote axial rather
23 than lateral paying out of the communication link 24 under
24 increase of distance of separation of assemblies 15 and 16.

25 Tube 30 and cylindrical body 35 of lifting body assembly 16
26 are releasably joined by a detente arrangement shown in detail in

FIGS. 3 and 3A. The detent arrangement 41 includes two or more downwardly-depending lugs 44 which resiliently deflect under a lateral force. In one successful embodiment, tube 30 is fabricated of lucite, and each lug 44 is formed as an extension of the main part of tube 30. A radially outwardly-projecting nib 45 is provided on each lug. The nibs may be formed, for example, as heads of round head screws driven into threaded holes formed in the lug.

Affixed within cylindrical body 35 is a transverse plate 46 with perforations 47 which are configured to receive the lugs 44, and which have sufficient radial expanse thickness that the nibs can pass therethrough. Tube 30 and cylindrical body 35 are releasably joined by insertion of the lugs 44 through the perforations 47. The radially outward peripheries of perforations 47 act as ridge members which, in cooperation with associated nib 45, provide a detent action that initially maintains body 35 joined to tube 30. A pulling force applied by communication line 24 from the submerged launch platform becoming taught will act upon lifting body 16, and in turn cause resilient lugs 44 to deflect so that the nibs will be able to pass through perforations 47. This allows damping motion assembly 15 and lifting body assembly 16 to separate. The resiliency characteristic of a wall of lucite tubing (out of which lugs 44 are formed) is suitable for providing this spring action.

1 The communication link 24 may be any convenient signal-
2 carrying link, including electrical wires, optical fibers or the
3 like.

4 Deployment of the sensor 10 will be described in connection
5 with FIG. 1 and also FIG. 2, which depicts the sensor 10 in a
6 deployed condition. With reference to those FIGS., immediately
7 prior to deployment, the operator will remove the nose cone 13,
8 use the switch 22 to activate the electronics package 14 and
9 replace the nose cone 13 to seal the chamber 20. In addition, if
10 the aft end 23 is covered by a cap for storage, the operator will
11 remove the cap. In this initial off-the-shelf condition, tube 30
12 is retained in a telescoped relationship within housing 12 by a
13 sliding fit provided by tube 30, slip ring 32 and the bore of
14 housing 12, and the lifting body is releasably joined to tube 30
15 by the detent arrangement. Thereafter, the operator will eject
16 the sensor 10 through a conventional aperture in the outer wall
17 of the submarine into the ocean environment.

18 After ejection, the buoyancy provided by the sealed chamber
19 20 will cause the sensor 10 to rise toward the ocean surface.
20 After the portion of the communication link 24 between the
21 lifting body assembly 16 and the submarine becomes taught, the
22 communication link 24 will exert a pulling force upon the detent
23 arrangement, pulling the lifting body assembly 16 out of the aft
24 end 23 (only FIG. 1) of the housing 11. The holding power of the
25 detent assembly is overcome when, due to the inherent resilience
26 of the material the tube is made of, the lugs 42 deflect inwardly

1 allowing nibs 42 to pass over the ridge member formed by the
2 outer radially edge of perforation 47. It will be appreciated
3 that since this operation is based on the resilient flexibility
4 of lugs 44, the detent arrangement is effectively a spring
5 release mechanism.

6 As the lifting body assembly 16 is drawn from the assembly,
7 the damping 15 is pulled downwardly in the housing 11, by the
8 pulling force of link 24 and by gravity force. The final
9 position of tube 30 is defined by the predetermined distance
10 which strap 33 permits tube 30 to travel, which distance is so
11 chosen that a significant portion (but less than one-half) of the
12 length of the tube 30 remains telescoped in housing 12. Slip
13 ring 32 drops under the force of gravity and it abuts against
14 inwardly directed collar-like restriction 18 at the aft end of
15 housing 11. It will be appreciated that, when slip ring 32 is in
16 this final position against restriction 18, it inhibits lateral
17 motion between distended tube 30 and cylindrical sidewall 12.
18 The inhibition of this lateral movement averts undesired
19 pendulous oscillation of a sensor 10 in response to sea motion.
20 Coil and spool unit 17a, which as stated earlier is slidably
21 mounted in the bore of tube 30, moves from an initial position in
22 which it is telescoped within tube 30 to a distended position
23 defined by abutment of transverse plate 34 against the inwardly
24 directed collar 30c at the aft end of tube 30.

25 After the sensor 10 reaches the ocean surface, the sensor
26 can begin generating vertical acceleration data caused by wave

1 motion on the buoyant chamber 20, for transmission over the
2 communication link 24 to the submarine. It will be appreciated
3 that the damping assembly 15, and more particularly tube 30,
4 constitutes a motion damping body which will suppress pitching
5 motion of sensor 10. This in turn enables sensor 10 to float on
6 the surface in a more nearly stable attitude in which the signal
7 being sent by sensor 10 to the linked submerged submarine will
8 more faithfully represent the surface sea motion. The damping
9 structure also functions to generally filter high-frequency
10 acceleration components, which distort the desired sea state
11 data. FIG. 4 depicts a functional block diagram depicting
12 apparatus which may be used to process signals received from the
13 sea state sensor depicted in FIGS. 1 and 2. With reference to
14 FIG. 4, the communication link 24 is connected to a strip chart
15 recorder 50, which can generate an analog recording of the signal
16 received from the sensor as a function of time, and an analog to
17 digital converter 51 which generates a digital data sequence
18 representing the amplitude of the signal from the sensor at
19 sequential points in time. A data logger 52 records the digital
20 data for processing by a computer 53. A printer 54 may provide a
21 hardcopy output from the computer. The analog to digital
22 converter 51 and data logger 52 may be provided in the
23 electronics package 14 on the sensor 10, and if so a battery 55
24 may be provided to power these elements.

25 As noted above, the computer 53 processes the digital data
26 received from the sensor 10. It will be appreciated that, since

the data received from the sensor 10 is acceleration data, and since acceleration is the second derivative of distance with respect to time, the ocean surface elevation information, or heave $n(t)$ is obtained by integrating the acceleration data $a_t(t)$ twice with respect to time

$$n(t) = \int a_z(t) dt dt \quad (1)$$

The frequency spectrum, which provides the distribution of energy content $N(t)$ as a function of frequency $F(a)$, is generated in a conventional manner using the FFT taken over a sampling period T as

$$F(\omega) = \frac{1}{T} \int_{-T/2}^{T/2} n(t) e^{-i\omega t} dt; n = 0, +_1, +_2, \dots \quad (2)$$

The energy spectrum, defined as

$$_F_m(\omega)^2 = \Phi_m(\omega) \quad (3)$$

is the contribution to the variance as a function of frequency. Since the acceleration applied by the wave motion is sinusoidal in nature, the integration in equation (1) will vary as $(1/a)^2$. The computer 53 applies corrections for estimates at low-frequencies, with the corrected estimate of the wave spectrum $>(a)$ being related to the raw spectrum $>_m(a)$ in equation (3) by

$$\Phi(\omega) = \frac{\Phi_m(\omega)}{R(\omega)H(\omega)} \quad (4)$$

where $R(a)$ is a frequency-dependent function related to sensor and electronics characteristics, and $H(a)$ is a frequency-dependent response function of the sensor 10 in the waves. These functions reflect non-linear sensor and wave effects at low and

1 functions reflect non-linear sensor and wave effects at low and
2 high frequencies.

3 The invention provides a number of advantages. In
4 particular, the damping assembly 15 and lifting body assembly 16
5 cooperate to ensure that the communication link 24 does not
6 abrade on the housing 11 when the sensor 10 is deployed. In
7 addition, the damping assembly 15 ensures that the sensor will
8 maintain a vertical position, and acts to filter high-frequency
9 accelerations which the sensor 10 is to ignore.

10 The preceding description has been limited to a specific
11 embodiment of this invention. It will be apparent, however, that
12 variations and modifications may be made to the invention, with
13 the attainment of some or all of the advantages of the invention.
14 Therefore, it is the object of the appended claims to cover all
15 such variations and modifications as come within the true spirit
16 and scope of the invention.

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2 IMPROVED SUBMARINE DEPLOYED SEA-STATE SENSOR

3
4 ABSTRACT OF THE DISCLOSURE

5 A submarine deployed sea-state sensor comprising an
6 elongated housing having a nose cone and an aft end, the housing
7 having a forward buoyant chamber for receiving an accelerometer
8 and for causing the sensor to be buoyed up to the surface, where
9 it will thereafter float in a spar buoy fashion. The housing
10 has, aft of the buoyant chamber, a damping assembly including a
11 longitudinally extending motion damping body, a communication
12 link deployment means and a lifting body, with both the damping
13 assembly and the lifting body being attached to a communication
14 link interconnecting the accelerometer and a submerged platform
15 so that, when the portion of the communication link between the
16 lifting body and the submerged platform becomes taught, the
17 lifting body is pulled from the housing and the motion damping
18 body is pulled by the lifting buoy into a distended position from
19 the main portion of the spar buoy. Initially, the motion damping
20 body is telescoped in the housing by a sliding fit between the
21 body and the housing, and the lifting body is releasably joined
22 to the motion damping body by a detent. The distended portion of
23 the motion damping body is defined by a fixed length strap
24 arrangement disposed within the sensor's housing which is
25 connected between the motion damping body and fixed structure
26 located toward the top of the housing.

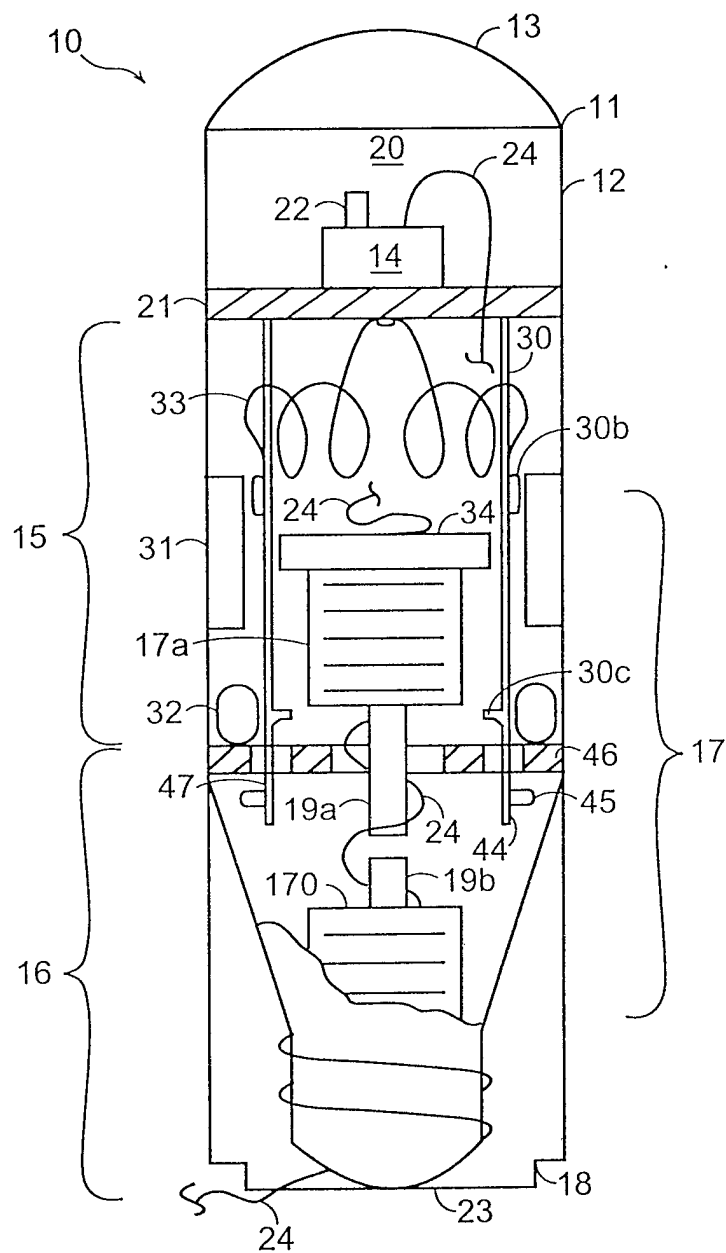
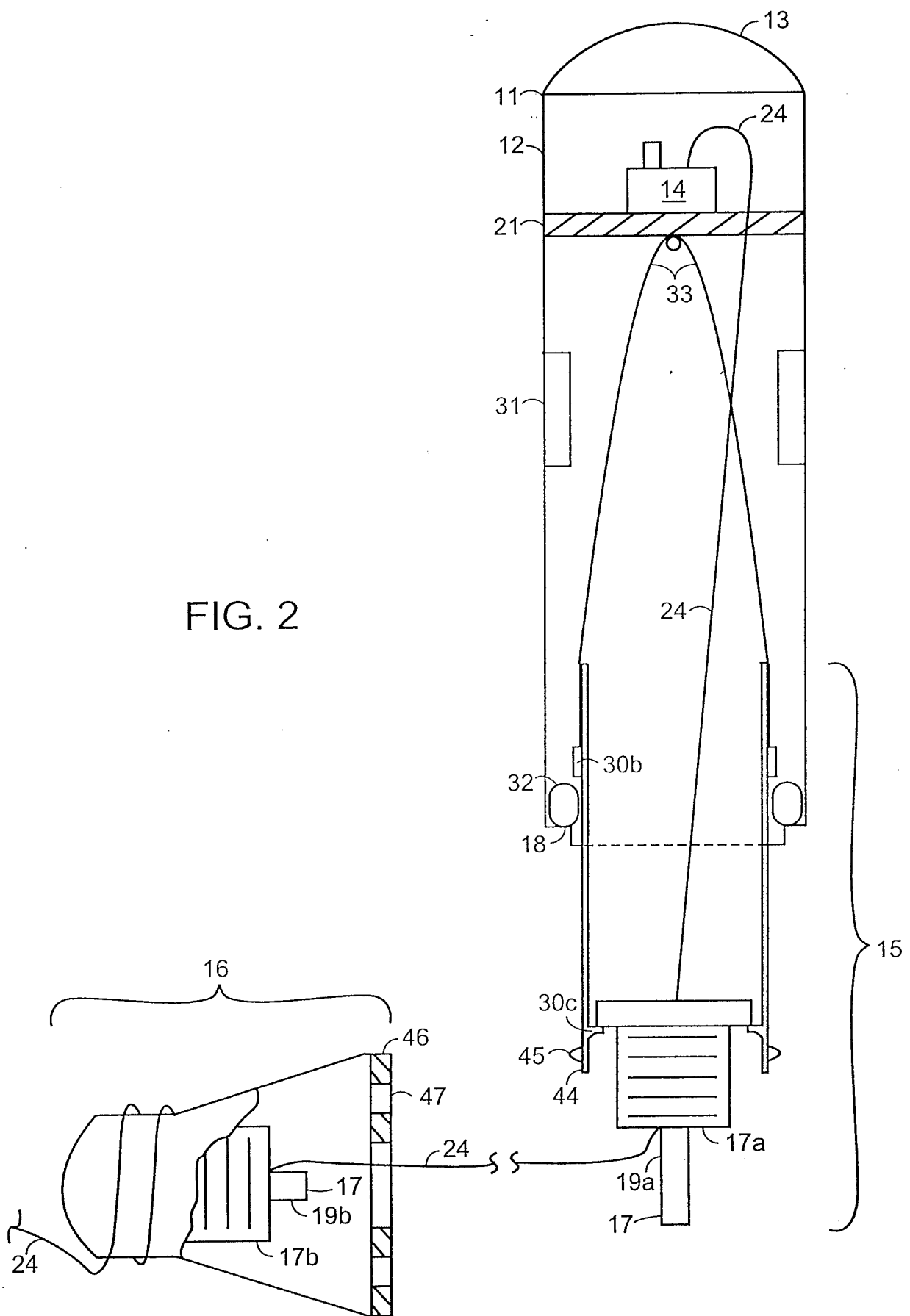


FIG. 1

FIG. 2



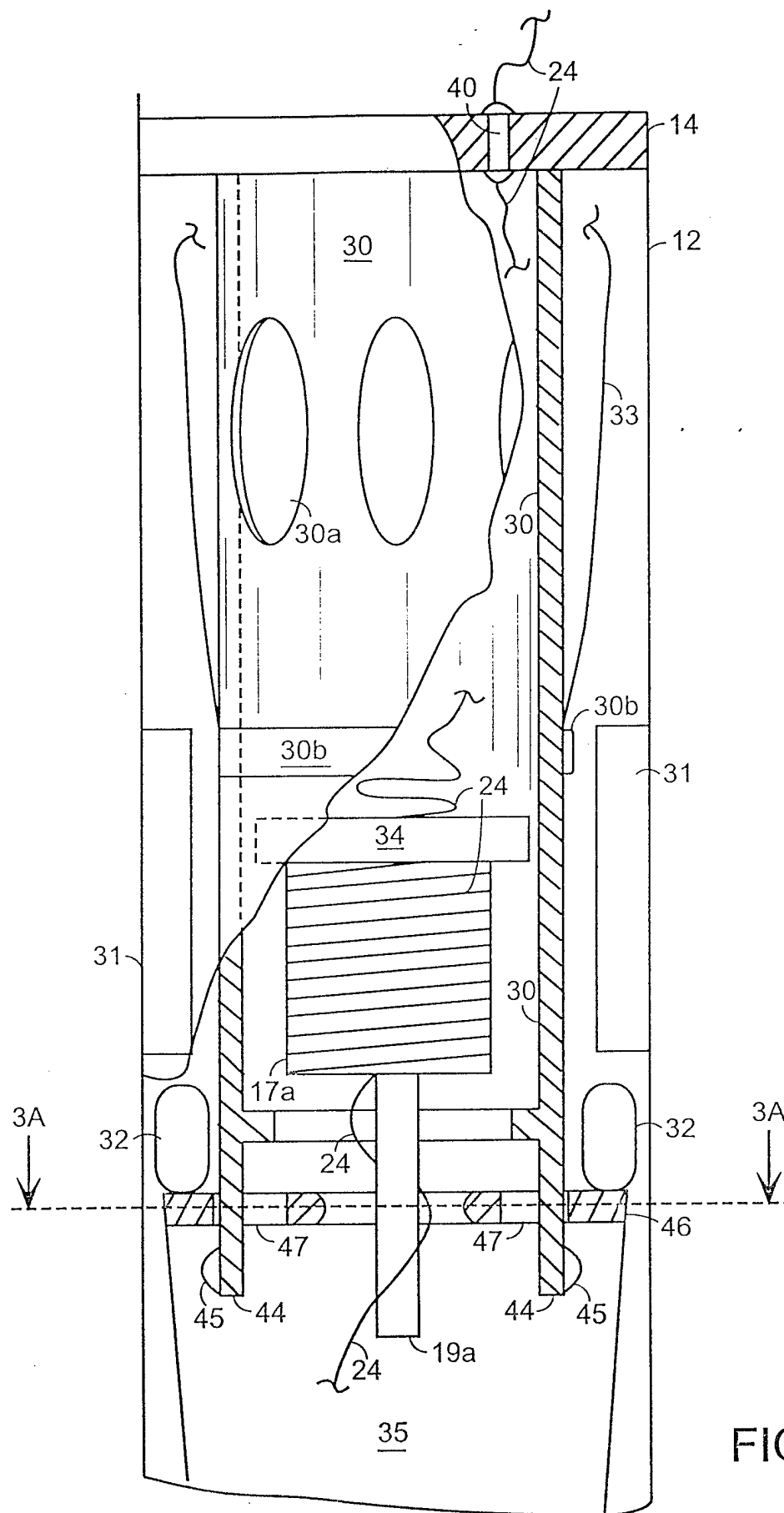


FIG. 3

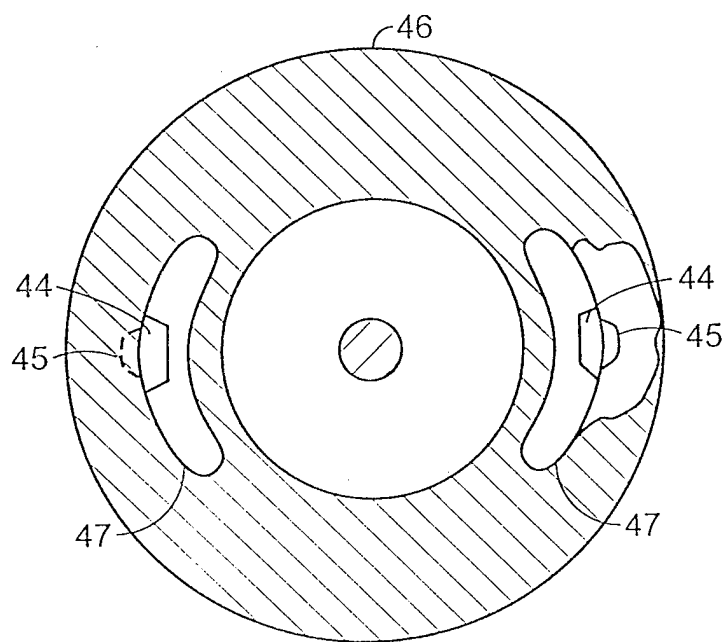


FIG. 3A

FIG. 4

