DEPARTMENT OF THE NAVY
OFFICE OF COUNSEL
NAVAL UNDERSEA WARFARE CENTER DIVISION
1176 HOWELL STREET
NEWPORT RI 02841-1708

IN REPLY REFER TO:

Attorney Docket No. 79247
Date: 6 June 2002

The below identified patent application is available for licensing. Requests for information should be addressed to:

PATENT COUNSEL
NAVAL UNDERSEA WARFARE CENTER
1176 HOWELL ST.
CODE 00OC, BLDG. 112T
NEWPORT, RI 02841

Serial Number	10/077,713
Filing Date	2/14/02
Inventor	Thomas R. Stottlemyer

If you have any questions please contact Michael J. McGowan, Patent Counsel, at 401-832-4736.

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

Attorney Docket No. 79247

WATER COLUMN SOUND SPEED PROFILING SYSTEM

TO ALL WHOM IT MAY CONCERN

BE IT KNOWN THAT THOMAS R. STOTTLEMYER, citizen of the United States of America, employee of the United States Government and resident of Mystic, County of New London, State of Connecticut has invented certain new and useful improvements entitled as set forth above of which the following is a specification:

MICHAEL J. MCGOWAN, ESQ.
Reg. No. 31042
Naval Undersea Warfare Center
Division, Newport
Newport, Rhode Island 02841-1708
TEL: 401-832-4736
FAX: 401-832-1231

Attorney Docket No. 79247

WATER COLUMN SOUND SPEED PROFILING SYSTEM

STATEMENT OF GOVERNMENT INTEREST

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

CROSS REFERENCE TO OTHER PATENT APPLICATIONS

Not applicable.

BACKGROUND OF THE INVENTION

(1) Field of the Invention

The present invention relates generally to determining sound speed in water, and more particularly to a method and system for determining the sound speed profile of a water column from a moving or stationary position at the water's surface or from some position under the surface.

(2) Description of the Prior Art

Knowledge of a water column's sound velocity profile is useful in predicting performance characteristics of a sonar system. Currently, such sound velocity profiling is accomplished using expendable bathythermometric devices, towed cables or laser Doppler velocimeters. Bathythermometric devices measure water temperature and salinity in determining the speed of sound in water. However, thermistors used to measure temperature have fairly slow response times leading to inaccuracies in sound velocity determination. Towed resonant bubble cables or acoustic sensor cables are tethered to a towing vessel and, therefore, possess all of the drawbacks of towed systems to include their size, equipment needed to store and deploy the towed cable, and the inherent problems associated with towing something through the water. Laser Doppler velocimeters are complex devices requiring a substantial amount of equipment.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a method and system for determining the sound speed profile of a water column.

Another object of the present invention is to provide a method and system for simply and efficiently determining the sound speed profile of a water column by minimizing the amount of equipment required to do so.

Still another object of the present invention is to provide a method and system for determining the sound speed profile of a water column that does not require the towing or tethering of any equipment to a vessel.

Other objects and advantages of the present invention will become more obvious hereinafter in the specification and drawings.

In accordance with the present invention, a system and method are provided for determining a sound speed profile of a water column. A sound source is deployed in the water at a first known location at a specified time. Deployment can occur from onboard a moving or stationary watercraft. The sound source is free to fall through the water at a known rate of descent. The sound source houses an acoustic source for transmitting acoustic pulses omnidirectionally therefrom at predetermined times after the specified time at which the sound source was deployed. An acoustic receiver located at a second known location detects each acoustic pulse. A processor coupled to the acoustic receiver and programmed with the specified deployment time and predetermined transmit times determines a time differential between each predetermined transmit time and a time of arrival for each corresponding acoustic pulse. Speed of sound for each portion of the water column is then determined as a function of i) the time differential, ii) the first and second known locations, and iii) the known rate of descent of the sound source.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages of the present invention will become apparent upon reference to the following description of the preferred embodiments and to the drawings, wherein corresponding reference characters indicate corresponding parts throughout the several views of the drawings and wherein:

FIG. 1 is a diagrammatic view of an embodiment of a system for determining the sound speed profile of a water column in accordance with the present invention;

FIG. 2 is a schematic view of an embodiment of the expendable acoustic pulsing device for deployment in a water column in accordance with the present invention; and

FIG. 3 is a schematic view of another embodiment of the acoustic pulsing device.

DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

Referring now to the drawings, and more particularly to FIG. 1, a diagram of one embodiment of a system and method for determining the sound speed profile of a water column in accordance with the present invention is illustrated. In this embodiment, a watercraft 10 is assumed to be moving right to left along the water's surface which is referenced by numeral 100. It is further assumed that watercraft 10 is moving at a known speed. At a predetermined time and known location, a sound source 20 is deployed (i.e. dropped) from watercraft 10. Sound source 20 can be manually or mechanically released from moving watercraft 10. However, as will be explained further below, scenarios of the present invention are not so limited. For example, watercraft 10 could be moving underwater or could be a stationary craft or buoy deployed at or under the water surface 100.

Sound source 20 is a device that descends via free fall through a water column that is to be profiled in terms of sound speed. In general, sound source 20 emits an omnidirectional broadband acoustic pulse at a number of known predetermined times after deployment. The predetermined times can be spaced evenly or unevenly. Another known quantity utilized by the present invention is the rate at which sound source 20 descends through the water. This essentially constant rate can be determined for any given body that defines sound source 20 as would be well understood by one of ordinary skill in the art.

Utilizing the various known quantities (i.e., location of deployment of sound source 20, rate of descent of sound source 20, time of deployment of sound source 20, times at which sound source 20 emits an acoustic pulse, and speed of watercraft 10), the present invention can determine a sound speed profile of a water column. Referring again to FIG. 1, the determination of sound speed for several consecutive portions of the water column through which sound source 20 falls will be detailed. First, assume that sound source 20 is dropped at a known time t=0 and a known location 30 at water surface 100 as watercraft 10 passes location 30. During a first predetermined time t_1, sound source 20 descends a distance d_1 that is determined/known based upon sound source 20's known rate of descent and the amount of time between t=0 to t_1. During this same amount of time, watercraft 10 has traveled a distance x_1 from location 30 that is determined/known based upon the known speed of watercraft 10 and the amount of time from t=0 to t_1.

Using standard geometric principles, an angle θ_1 can be determined where θ_1 defines the angle between the vertical descent of sound source 20 and the location of watercraft 10 at time t_1 relative to sound source 20. At time t_1, sound source 20 emits its first omnidirectional acoustic pulse that is detected at watercraft 10 by an acoustic receiver 12 mounted on watercraft

10. Acoustic receiver 12 could be the existing fathometer used by watercraft 10. Detection of the acoustic pulse is time stamped by a processor 14 coupled to acoustic receiver 12.

Processor 14 is programmed with the time t=0 and the subsequent predetermined times t_1, t_2,..., etc. at which an acoustic pulse will be produced by sound source 20. Accordingly, processor 14 can determine a time interval T_1 defining the time it takes the first acoustic pulse to travel from sound source 20 to acoustic receiver 12. To determine sound speed V_1 in the portion of the water column defined by descent distance d_1, processor 14 applies the following relationship

$$V_1 = d_1/(T_1\cos\theta_1) \qquad (1)$$

where the expression $T_1\cos\theta_1$ represents the vertical component of the time interval T_1.

Analogous logic can be applied at subsequent predetermined times t_2 and t_3 to determine sound speeds V_2 and V_3, respectively, in the portions of the water column traversed by sound source 20 from times t_1 to t_2 and then times t_2 to t_3. Specifically, using standard geometric principles,

$$V_2 = (d_2-d_1)/(T_2\cos\theta_2-T_1\cos\theta_1) \qquad (2)$$

and

$$V_3 = (d_3-d_2-d_1)/(T_3\cos\theta_3-T_2\cos\theta_2-T_1\cos\theta_1) \qquad (3)$$

The above described approach can be extended to each subsequent portion of the water column defined by descending sound source 20.

Although sound source 20 could be realized by a variety of designs without departing from the scope of the present invention, a simple, reliable and inexpensive embodiment thereof will be explained herein. Referring now to FIG. 2, sound source 20 is defined externally by a smooth hydrodynamic body 21 that will descend through a water column in a stable fashion. Tail fins 22 would typically be provided at the aft end of body 21 to aid stability. Body 21 includes a water tight compartment 23 housing electronics components and a nose cone 24 that floods with water via flood ports 25 in nose cone 24. That is, when body 21 is deployed in the water, nose cone 24 fills with water. Nose cone 24 is constructed using an acoustically transparent material such as urethane or other similar material having a specific acoustic impedance that is close to that of water. Mounted in free-flooding nose cone 24 is an electrode pair 26 having a spark gap 27 therebetween. Mounted in watertight compartment 23 are timing electronics 28 coupled to a power source 29 (e.g., a battery) which, in turn, is coupled to electrode pair 26. Compartment 23 can be fitted with an epoxy or other similar material so that body 21 would not have to be a pressure vessel.

At the predetermined times t_1, t_2, t_3, etc., provided by timing electronics 28, power source 29 sends power to electrode pair 26 causing a spark in spark gap 27. The spark forms a vapor cavity or bubble in the water that flooded nose cone 24. The bubble collapses thereby producing the short broadband acoustic pulse (e.g., ranging over several kilohertz) used by the present invention.

The advantages of the present invention are numerous. A sound speed profile of a water column is determined simply and reliably with a minimal amount of equipment. No tethering or towing of equipment is required as the present invention relies on acoustic telemetry as opposed to electric (wire) telemetry. Further, the problems associated with measuring water temperature as a means for determining sound speed are eliminated. The present invention can be used from a moving or stationary watercraft that is deployed at or under the water's surface.

Although the present invention has been described relative to a specific embodiment thereof, it is not so limited. For example, as illustrated in FIG. 3, the spark gap type of sound source could have its free-flooding volume positioned in another part of the sound source's body. In FIG. 3, a sound source 40 has a body 41, tail fins 42 and a watertight compartment 43. A free flooding compartment 44 is defined at a central portion thereof that floods via ports 45 formed therein. An electrode pair 46 is disposed in free flooding compartment 44 and is positioned at or near the center of gravity of body 41 so that bubble production and collapse minimally impacts the stability of sound source 40 as it free falls through a water column.

Sound source 40 further depicts another option for the present invention in cases where sound speed profiles at great depths must be determined. That is, as depth increases, hydrostatic pressure acting on the bubble being produced by electrode pair 46 increases thereby reducing the diameter of the bubble and the acoustic level it produces on collapse.

Accordingly, timing and power level electronics 48 can be used to control power source 49 in terms of both time of activation of electrode pair 46 and level of voltage supplied thereto. In this way, at increasing times/depths, a greater amount voltage could be applied to electrode pair 46 to mitigate the depth effects on the bubble produced thereby.

It will thus be understood that many additional changes in the details, materials, steps and arrangement of parts, which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims.

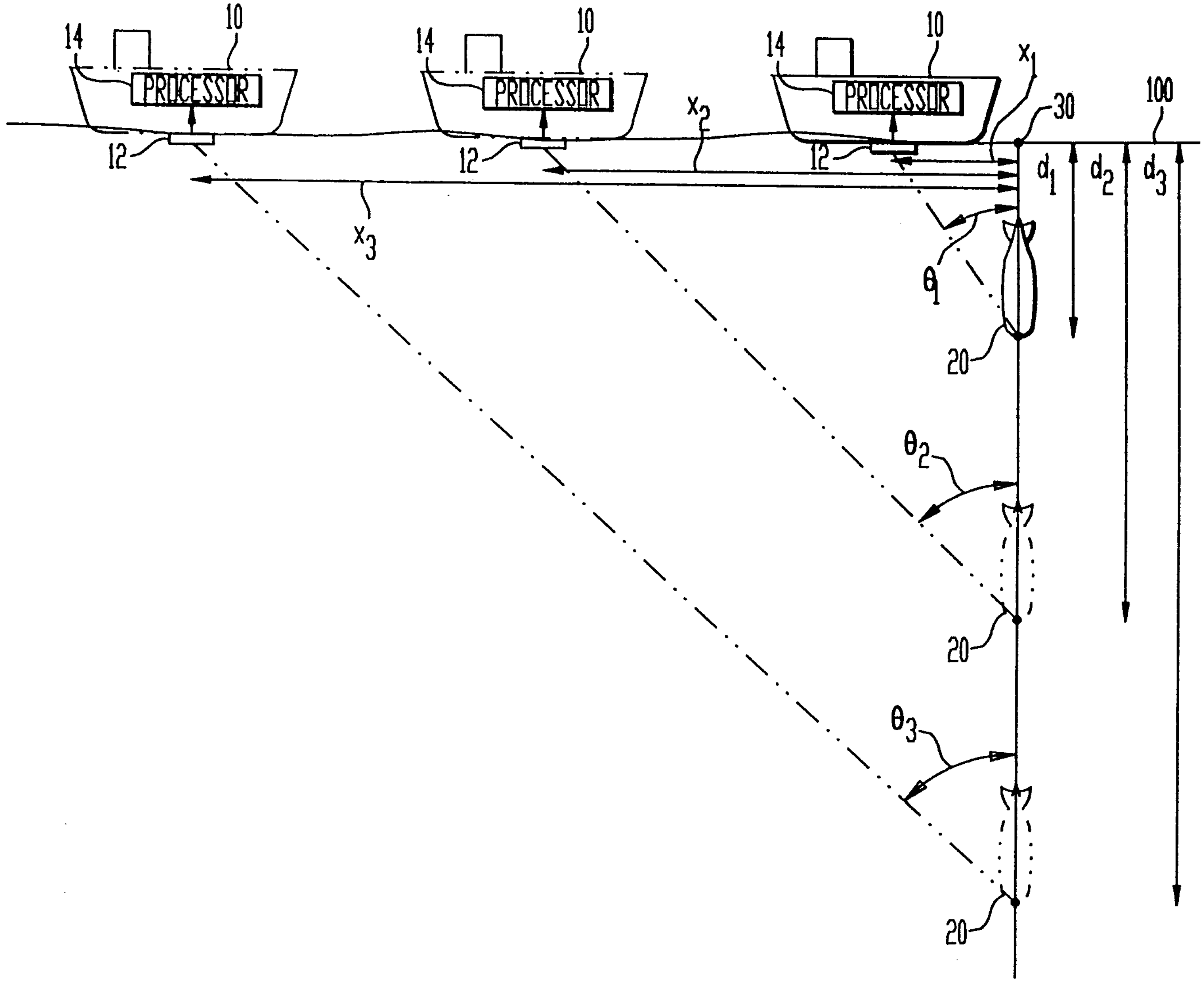
Attorney Docket No. 79247

WATER COLUMN SOUND SPEED PROFILING SYSTEM

ABSTRACT OF THE DISCLOSURE

A system and method are provided for determining a sound speed profile of a water column. A free falling sound source is deployed in the water at a known location and time. The sound source transmits acoustic pulses omnidirectionally therefrom at predetermined times after deployment. An acoustic receiver located at a known location detects each acoustic pulse. The time differential between each predetermined time and a time of arrival for each subsequent acoustic pulse is determined. Speed of sound for each portion of the water column is then determined as a function of the time differential, the known locations of sound source deployment and the acoustic receiver, and the known rate of descent of the sound source. The sound source can be constructed from a hydrodynamic body housing a power source, timing electronics, and spark gap electrodes. A bubble, generated by the spark gap electrodes, implodes to create the acoustic pulse detected by the receiver.

FIG. 1



14
10
PROCESSOR
12
14
10
PROCESSOR
12
14
10
PROCESSOR
12
x1
x2
x3
30
100
d1
d2
d3
θ1
θ2
θ3
20
20
20

FIG. 2

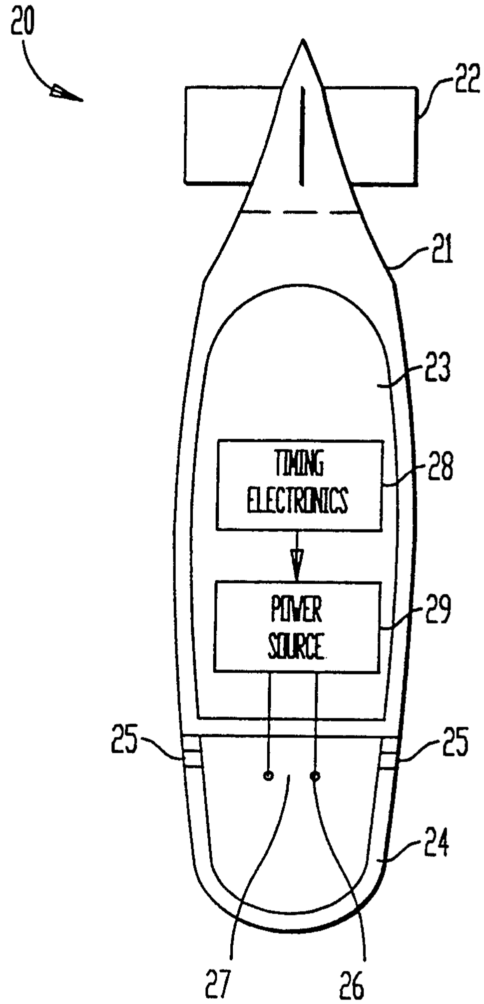
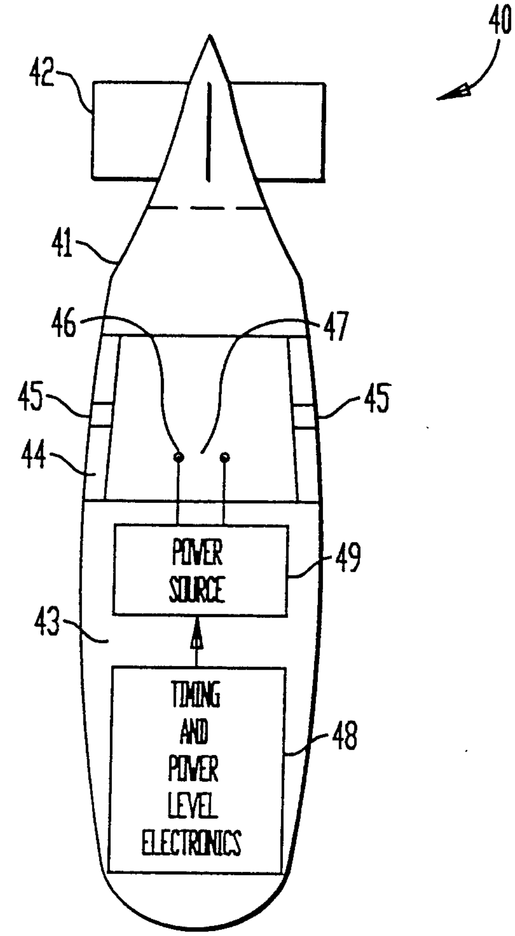

20
22
21
23
TIMING ELECTRONICS
28
POWER SOURCE
29
25
25
24
27
26

FIG. 3


40
42
41
46
47
45
45
44
POWER SOURCE
49
43
TIMING AND POWER LEVEL ELECTRONICS
48