United States Patent [19]

D'Amico et al.

[11] **3,756,345**

[45] **Sept. 4, 1973**

[54] **UNDERWATER ACOUSTIC DEVICE**

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[22] Filed: **Feb. 10, 1972**

[21] Appl. No.: **225,149**

[52] **U.S. Cl.** ..... **181/33 G**, 181/33 A, 181/.5 A, 340/5 A, 340/8 S

[51] **Int. Cl.** **G01v 11/00**, G10k 11/04

[58] **Field of Search** ..... 181/33 A, 33 G, .5 A; 340/5 A, 8 S, 10, 16, 14

[56] **References Cited**

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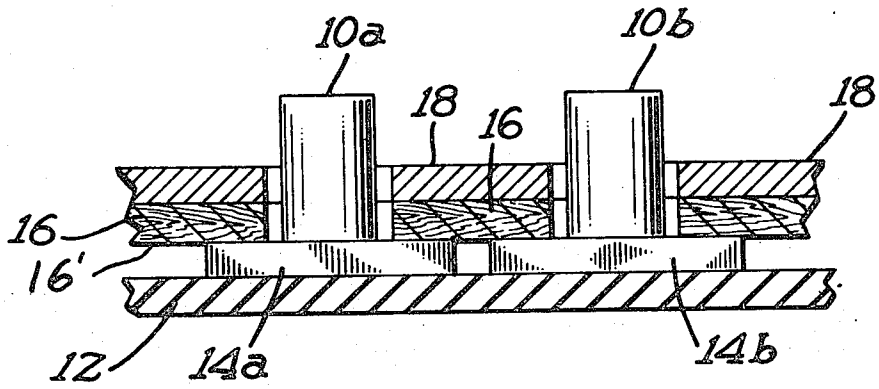
[57] **ABSTRACT**

A pressure insensitive underwater acoustic element useful as an acoustic reflector or an acoustic decoupler uses a body of balsa wood which is isostatically pre-compressed to between about 2,500 pounds per square inch and about 20,000 pounds per square inch.

5 Claims, 5 Drawing Figures



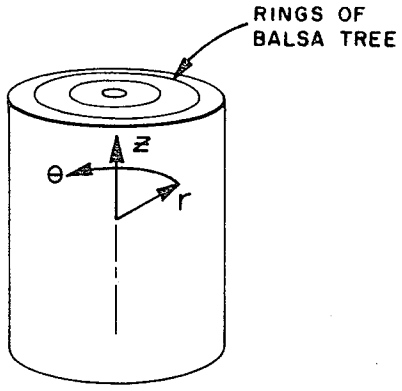


Fig 1

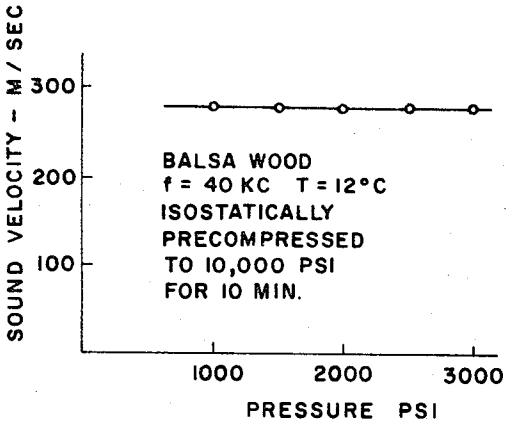


Fig 2

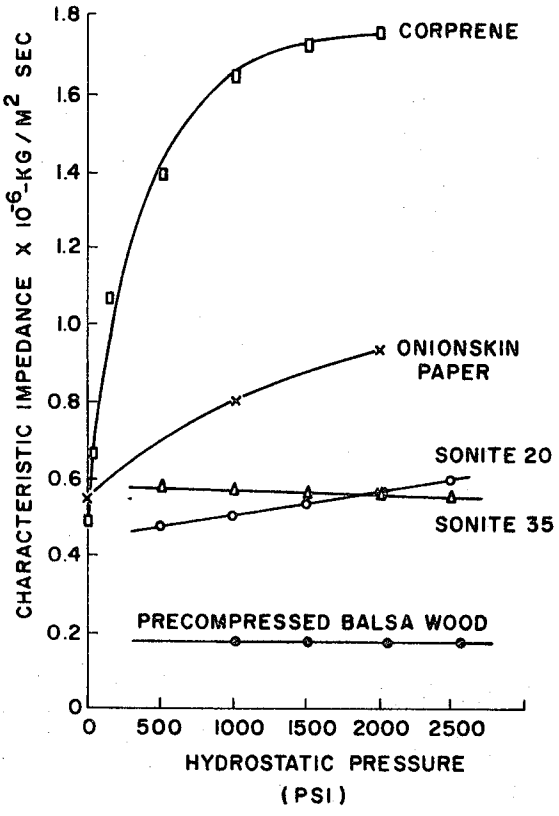


Fig 3

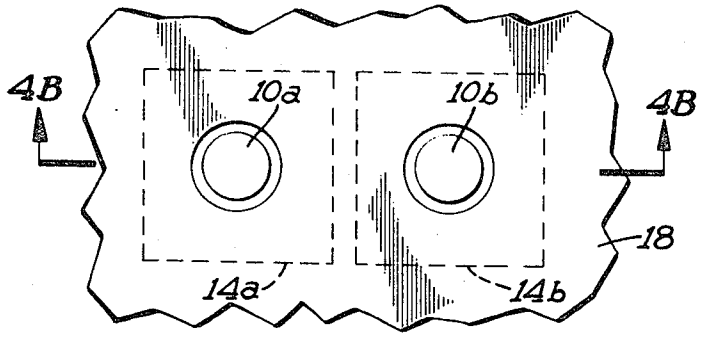


Fig 4A

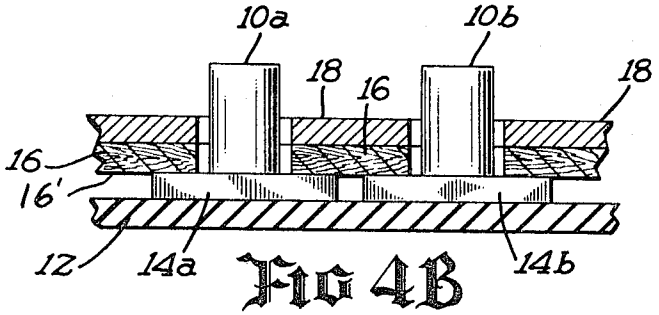


Fig 4B

UNDERWATER ACOUSTIC DEVICE

BACKGROUND OF THE INVENTION

This invention relates to an underwater acoustic device suitable for use in planar systems. In particular, it relates to a pressure insensitive acoustic device useful as a reflector or decoupler at great depths in the ocean.

In the design of sonar devices, it is often desirable to isolate the transducer elements acoustically from each other and from the structure of the device. This isolation is normally accomplished by acoustic decoupling materials, which provide acoustic isolation through impedance mismatch and internal attenuation.

The characteristic impedance, ρc, of any material may be represented as the product of the material's density ρ and sound velocity c. For a free plane wave, this is also equal to the specific acoustic impedance. When the acoustic impedance of one material is the same as that of an adjacent material, the materials are said to be "matched"; when the acoustic impedances of the two materials are different, the materials are "mismatched".

Two of the desired properties of an acoustic decoupler are first, an insertion loss of at least 30 db per centimeter through a combination of reflection and absorption, and second, stable acoustical and mechanical properties with temperatures from 0° C to 30° C, and with pressures or uniaxial stresses, or both, up to 10,000 psi. Heretofore, no acoustic decoupler material has been able to satisfy the above requirements, although a large variety of materials have been used.

One of the best currently available decoupler materials is Sonite, manufactured by Johns Manville Company. The acoustical and mechanical properties of Sonite were described by R. W. Higgs et al, in the *Journal of the Acoustic Society of America* (JASA), Volume 50, 946–954, Sept. 1971. Sonite has the disadvantage of having a high characteristic impedance at high ambient pressures. For projected deepocean uses, decoupler materials with a lower characteristic impedance must be found or designed.

Another decoupler material is onionskin paper, which is precompressed to a stress level above that which it will experience in a deep ocean device. The acoustic decoupling properties of onionskin paper were described by R. W. Higgs and L. J. Eriksson in JASA, Volume 46, 211–215, July 1969. The main disadvantage with onionskin paper is that it allows the directivity pattern and frequency-response curve to change with pressure.

Another material which has been studied is Corprene DC-100, made by Armstrong Cork Company, which is a polychlorophene-cork composite. Corprene is a satisfactory acoustic decoupling material at pressures up to a few hundred psi as described by Higgs and Eriksson JASA, Volume 46, 1254–1258, November 1969. Above these low pressures, Corprene ceases to provide the isolation necessary for proper acoustic decoupling, thereby causing the directivity pattern and frequency response to change with pressure. Therefore, it too is unsuitable for an acoustic decoupler capable of use at great depths of the ocean.

Balsa wood (*Ochroma lagopus*) is one of the lightest commercially available woods in the world. It grows extensively in central and northern South America. Nonprecompressed balsa wood has been used as an acoustic decoupler. In *Sonics* by T. F. Hueter and R. H. Bolt, an ultrasonic device is shown and described on pages 259 and 260 which utilizes an open pill box, filled with cork or balsa wood, which is pressed against a piezolectric crystal by a spring.

SUMMARY OF THE INVENTION

With the present invention, a pressure insensitive underwater acoustic device useful as a reflector or decoupler is provided. It has been discovered that balsa wood, when precompressed to between about 2,500 pounds per square inch and about 20,000 pounds per square inch has a low characteristic impedance capable of providing an insertion loss of at least 30 db per centimeter. The precompression of the balsa wood may be achieved for example by isostatic or unaxial methods, and may be achieved through a single pressure cycle or a number of pressure cycles. In addition, any changes in the acoustic properties of precompressed balsa wood with pressure are small enough to permit the insertion loss requirements to be maintained. Therefore, acoustic decouplers or reflectors made from precompressed balsa wood are capable of operation at great depths of the ocean. Prior to this invention, no known acoustic decoupling and reflecting material had these properties.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 diagrammatically shows a section of a balsa tree from which the acoustic device of the present invention can be fabricated.

FIG. 2 shows the sound velocity in the direction normal to the grain of precompressed balsa wood as a function of pressure.

FIG. 3 shows the acoustic impedance of Corprene, Onionskin paper, Sonite, and precompressed balsa wood as a function of pressure.

FIGS. 4*a* and 4*b* show top and cross-sectional views of a sonar system including the acoustic decoupler of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIG. 1 is shown a section of a balsa tree from which the acoustic devices of the present invention are made. For the purposes of this specification, cylindrical coordinates are used to describe the various directions of sound propagation. The z direction is along the wood fiber or grain of the tree. The θ direction is along the rings of the tree, and the r direction is across the rings.

It has been found that balsa wood has transverse isotropy. In particular, the longitudinal sound velocity in the r and θ directions is much less than the sound velocity in the z direction.

Balsa wood is commercially available in a range of densities from less than 0.1 *g/cc* to 0.3 *g/cc*. In one successful embodiment of the present invention, balsa wood having a density of about 0.09 *g/cc* is isostatically precompressed to a precompression pressure of about 10,000 psi for 10 minutes. The resulting precompressed density is 0.68 *g/cc*.

The longitudinal sound velocity in the r and θ directions was measured using a water-filled impedance tube technique described by Higgs et al, in JASA, 49 (A), 1971. The measurements were made at 40 kHz with the temperature being held constant at 12° C. The pressure was varied from 1,000 to 3,000 psi. FIG. 2 shows the sound velocity in the r and θ directions as measured by

the impedance tube technique. It can be seen that the velocity is approximately 280 meters per second over the entire range. The pressure insensitivity shown in FIG. **2** is highly unexpected.

The longitudinal sound velocities in precompressed balsa wood were also measured using a resonant tube technique and a buffer rod technique. The resonant tube measurements were made at 1.2 kHz and 1,000 psi. The longitudinal sound velocity in the r and θ directions was found to be 272 meters per second, which agrees very closely with the results of the impedance tube measurements.

The buffer rod measurements were made at 1 MHz and at room temperature and pressure. The longitudinal sound velocity in the r and θ directions was measured at 335 meters per second while the velocity in the z direction was 4,720 meters per second.

Because of the high sound velocity along balsa wood's fiber structure (the z direction), sound propagation in that direction must be avoided in decoupling applications. Therefore, the precompressed balsa wood body used as a decoupler must be oriented such that the longitudinal sound waves impinging on the decoupler are essentially normal to the z direction.

FIG. **3** shows the acoustic impedance as a function of pressure for Corprene, onionskin paper, two different samples of Sonite (designated "Sonite **20**" and "Sonite **35**") and the precompressed balsa wood sample previously discussed. It can be seen that the precompressed balsa wood has a considerably lower characteristic impedance.

FIGS. **4A** and **4B** show top and cross-sectional views of a typical sonar assembly in which the precompressed balsa wood decoupler is used. Transducers **10***a* and **10***b* are typically made from piezolectric or piezomagnetic materials. Rubber window **12** protects the transducer assembly and improves coupling and directivity of the sound waves. The matching elements **14***a* and **14***b*, are typically a quarter wavelength section of aluminum. Since aluminum has a characteristic impedance which is almost the geometric mean of the impedances of a typical piezolectric crystal and a rubber window, and since the thickness of each aluminum matching element is one quarter wavelength, aluminum matching elements **14***a* and **14***b* greatly improve the coupling between crystals **10***a* and **10***b* and the water.

Balsa wood decoupler **16** is positioned between aluminum matching elements **14***a* and **14***b* and steel support **18.** The precompressed balsa wood is oriented such that the z direction is parallel to the surface of decoupler **16.** A large acoustic impedance mismatch occurs between aluminum matching elements **14***a* and **14***b* and balsa wood decoupler **16.** Therefore, very little of the longitudinal sound waves produced by transducers **10***a* and **10***b* propagate into steel support **18.**

For maximum transmission or insertion loss, the thickness of balsa wood decoupler **16** should be $n\ \lambda/4$, where n is an odd integer. λ is the acoustic wavelength in the balsa wood calculated at the midband frequency of the sonar system.

Although acoustic decouplers have been specifically discussed, the unique acoustic properties of precompressed balsa wood provide a solution to another long standing problem in sonar systems. This is the need for an acoustic reflector material for use at great depths in the ocean. For example, certain acoustic underwater systems may require a parabolic reflector. As a reflector in water, precompressed balsa wood with a characteristic impedance of $0.2 \times 10^6\ kg\ m^{-2}\ sec^{-1}$ provides a pressure reflection coefficient of 0.76. This pressure reflection coefficient is unexpectedly high for a material which can withstand pressures up to 10,000 psi.

If precompressed balsa wood is used as an underwater reflector, the balsa wood must be coated with a water impervious coating to prevent water contamination. It has been found that a thin layer **16'** of RTV-112 silicone rubber provides the necessary protection from water contamination.

It is readily apparent to those skilled in the art that many modifications of the present invention are possible. It should therefore be understood that the invention is not to be limited by the embodiments shown, but only by the scope of the attached claims.

The embodiments of the invention in which an exclusive property or right is claimed are defined as follows:

1. A pressure insensitive underwater acoustic device comprising a body of balsa wood precompressed to between about 2,500 pounds per square inch and about 20,000 pounds per square inch, the body being oriented such that the direction along the grain of the balsa wood is essentially normal to longitudinal acoustic waves impinging on the device.

2. The pressure insensitive underwater acoustic device of claim **1** wherein the device has a thickness essentially equal to $n\ \lambda/4$, where n is an odd integer and λ is the acoustic wavelength in the balsa wood calculated at the midband frequency of the longitudinal acoustic waves impinging on the device.

3. The pressure insensitive underwater acoustic device of claim **1** wherein the device is an acoustic decoupler.

4. The pressure insensitive underwater acoustic device of claim **1** wherein the device is an acoustic reflector.

5. The pressure insensitive underwater acoustic device of claim **4** and further comprising a water impervious coating over the body of balsa wood for preventing water contamination thereof.

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