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TECHNICAL NOTE 100-1

Underwater Acoustic and Shock Absorption Performance of Syntactic Foam

INTRODUCTION

Syntactic foam is a lightweight, high strength composite material frequently used in the sea for floats and buoys, to support instruments, as a submarine void filler, for encapsulating hydrophones, and so on. In many cases, the acoustic and shock absorption characteristics of syntactic foam are as important as its efficiency in supplying buoyancy.

THE TRANSMISSION OF SOUND

Sound is any mechanical disturbance transmitted through matter. The speed with which sound is transmitted is a chaacteristic of the material in question, proportional to the modulus or stiffness of the material and inversely proportional to its density. For example, the speed of sound in sea water can be calculated as follows:

(1)
$$C = \sqrt{\frac{K}{\rho}} = \sqrt{\frac{300{,}000}{9 \times 10^{-5}}} = 57{,}735 \text{ in/sec}$$

where:

- C = Speed of sound in sea water, approx. 57,735 in/sec, or 4,800 ft/sec, disregarding effects of temperature, salinity, and pressure.
- K = Bulk modulus of sea water = 300,000 psi.
- ρ = Density of sea water, based on a specific weight of 64 lbs./cu.ft. = 9×10^{-5} slugs/cu.in.

Syntactic foam is a solid with a bulk modulus similar to that of sea water (in some syntactic materials, the modulus is actually higher than that of water), and a density much less than that of water. As Equation 1 shows, this results in a high speed of sound. Cuming Corporation's HP-42 syntactic foam, for example, transmits sound at nearly 7,000 ft/sec.

The high speed of sound transmission through syntactic foam is useful in at least two important ways. First, it enables very effective lenses to be made of syntactic foam for the purpose of focusing, spreading, or collimating sonar waves. Second, it permits syntactic foam to be made with an impedance closely matched to that of water, thus minimizing reflection at the water/syntactic interface.

ACOUSTIC IMPEDANCE

Acoustic impedance is the ratio between particle pressure and velocity. It is most commonly calculated as the product of density and sound speed in MKS units, the familiar "rho-see" of underwater acoustics:

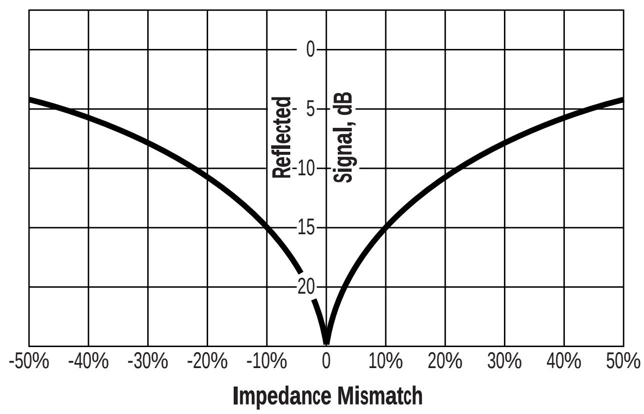
(2) $z = \rho c = (1.026) \times (1{,}463) = 1{,}500$ rayls.

where:

- z = Acoustic impedance of sea water, rayls.
- ρ = Specific gravity of sea water = 64/62.4 = 1.026.
- C = Speed of sound in water = 4,800 fps = 1,463 m/sec.

Similarly, the impedance of HP-42 syntactic foam can be calculated and found to be 1,440 rayls, a difference of only 4% from the impedance of sea water. Referring to Figure 1, it can be seen that this results in the reflected signal being 17 dB down from the incident signal, meaning that 98% of the sound energy will pass through the syntactic foam/sea water interface.

Figure 1 IMPEDUS MATCH vs. REFLECTION



LOSS FACTOR

Most types of syntactic foam are rigid, highly elastic, low-loss materials: in other words, they are transparent to sound energy. Acoustic loss factors for solid syntactic foam are typically 0.01-0.02. The amount of energy lost per pass through a piece of HP-42 syntactic foam can be estimated thusly:

(3)
$$A = \frac{27.3 \text{ FNT}}{C} = \frac{27.3\ (1{,}000) \times (0.01) \times (0.083)}{7{,}000} = 0.003 \text{ dB/in.}$$

where:

- A = Attenuation, dB.
- F = Frequency, Hertz.
- N = Loss Factor.
- T = Thickness, feet.
- C = Speed of sound in HP-42, ft/sec.

Combining effects of reflection at both the inner and outer faces, plus internal losses, it can therefore be estimated that at least 95% of a 1.0 RHz sonar signal will pass through a block of HP-42 syntactic foam 6.00" thick.

EFFECTS OF OTHER FILLERS

The materials discussed above are all so-called "solid" syntactic foams, in which the only fillers are tiny hollow glass microspheres. Because microspheres are so small, with diameters in the 100-200 micron range, they have little or no effect on sound transmission at common sonar frequencies. Larger fillers, such as fiberglass macrospheres with diameters ranging from 0.25” to 3.0011, may have a significant effect. Syntactic foam filled with large macrospheres tends to be a strong scatterer of sonar signals, in much the same way that a panel of frosted glass diffuses light.

Other fillers which alter the density of syntactic foam or change its elastic properties will also affect its acoustic performance. In some cases, the addition of specially selected fillers can give syntactic foam desirable characterisitics of sound and vibration damping and isolation. It is also possible to create syntactic materials which function as sonar absorbers, as discussed in the next section. Table 1 below summarizes the Cuming Corporation syntactic foam products line with suggested acoustic applications.

SONAR ABSORBERS

Making an efficient, broadbanded sonar absorber presents a number of technical challenges. Most absorptive materials do not have the requisite impedance, and rigid materials are not lossy enough. In some cases, scattering can be used to enhance absorption, but this is not always practicable. Even more difficult are the effects of wavelength: absorbers designed for high frequencies are ineffective at low frequencies. Finally, whatever system is used, it must have good hydrostatic strength so that it may be used deep in the sea. The most promising development in this area is a new family of composite materials employing rigid syntactic foam in combination with a variety of fillers and ingredients.

The addition of suitable additives to the syntactic system can provide a controlled amount of scattering or absorption. Reducing the elastic modulus of the resin binder to create a more “rubbery” foam will introduce acoustic loss. A truly broadbanded sonar absorber with good hydrostatic strength can be made by dispersing suitably-sized elastomeric particles in a syntactic foam matrix, as shown in Figure 2. Loss factors in the range of 1.0 - 2.0 have been achieved. Using these principles, successful underwater sound absorbers have been made for a variety of military and civilian applications.

Figure 2 EXAMPLES OF SONAR ABSORBING MATERIALS

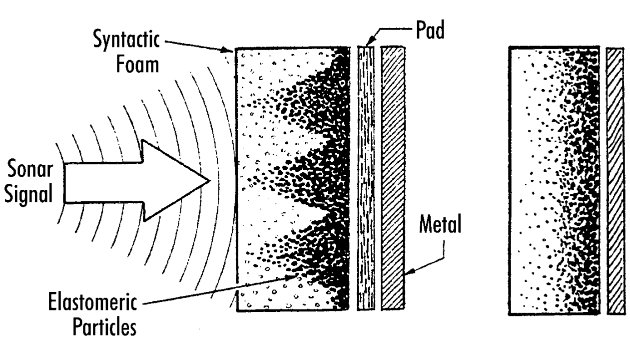
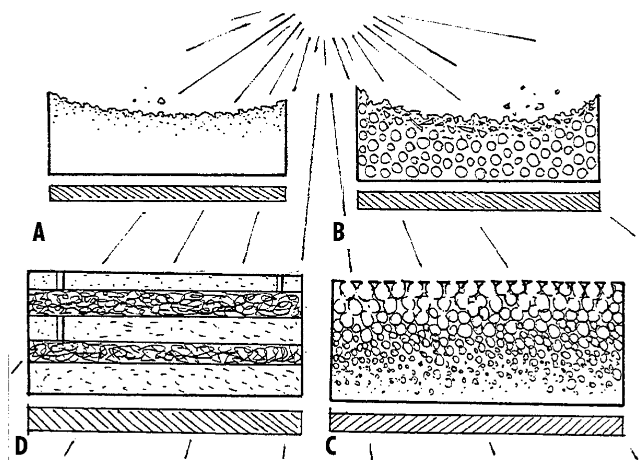


Figure 3 EXAMPLES OF UNDERWATER SHOCK WAVE ABSORBERS



UNDERWATER SHOCK

Yet another type of acoustic energy is the high-intensity shock wave generated by an underwater explosion, or “undex”. Merely reflecting or transmitting the energy of the undex shock wave is not sufficient. What is desired is a highly ineleastic transaction that results in much of the energy being lost or dissipated. As described above, sonar absorbers achieve this with a graduated structure combining an impedance-matched syntactic foam front face and a lossy internal filler which exhibits high levels of hysteresis loss at sonar frequencies. In other words, internal friction gradually transforms acoustic energy into thermal energy.

Unfortunately, sonar-type absorbers cannot adequately attenuate the high-power/short-pulse shock waves of an undex. It is necessary to provide for some kind of gross inelastic volume change to extract the energy of the shock wave. The cellular structure of syntactic foam can be adapted for this purpose. Figure 3 illustrates such behavior for (a) microsphere fillers only, and (b) combined microsphere and macrospheres. A graduated structure combining a variety of sizes and strengths of spheres is most effective. An obvious drawback of this mechanism is that its usefulness is limited to a single explosion, or, at best, a few explosions, before needing repair or replacement.

If reuseability is a requirement, another loss mechanism, such as viscous damping, may be necessary. Figure 3 illustrates two possible designs of viscous damping attenuators. In Figure 3 (c), a reticulated or graduated open-cell structure traps the shock wave in a labyrinth of small voids. In Figure 3 (d), multiple layers of rigid and flexible material compress accordion-fashion to absorb the shock wave. The latter design must be vented and pressure-balanced to compensate for the effects of depth, and the arrangement of the layers must be tuned to respond most effectively to a particular threat.

Table 1 ACOUSTIC APPLICATIONS OF SYNTACTIC FOAM

C-Float Designation	HP	GP	LD	UFO
Technical Bulletin No.	125	135	145	155
Type of Material	Rigid Syntactic	Rigid Syntactic	Rigid Syntactic	Flexible Syntactic
Fillers	Glass Microspheres	Glass Microspheres + 0.50" Macrospheres	Glass Microspheres + 3.00" Macrospheres	Glass Microspheres
Principal Characteristic	Transparents	Scatterer	Scatterer	Lossy
Suggested Uses	Sonar, Windows, Lenses Hydrophone Encapsulants	Targets & Undex Absorbers	Targets & Undex Absorbers	Noise Dampers, Sonar Absorbers & Isolators