ACOUSTICAL PROPERTIES OF SORBOTHANE

Abstract

This report gives a qualitative analysis of the acoustic properties of Sorbothane in water at frequencies greater than 5,000 kHz and in air for frequencies less than 15 kHz. Measurements indicate that Sorbothane which lacks hydrogen bonding has very high acoustic loss, >130 dB per cm. at 500 kHz, and a specific acoustic impedance similar to that of water. At 5 kHz the transmission loss into air is estimated to be greater than 40 dB/cm. and rises rapidly with frequency. This new family of Polyurethane elastomers should find large application in areas where substantial acoustic energy must be absorbed at high-frequencies, such as in anechoic chambers and tanks.

Introduction

This investigation into the high-frequency acoustic properties of a new family of Polyurethane elastomers which are marketed under the Trade Name – Sorbothane, has been undertaken to discover if Sorbothane is a suitable material for lining the walls of an anechoic water tank. The author and his colleagues at UCL are involved in characterizing fibre-optic hydrophones. A serious problem exists with the 6 ft x 3½ ft x 3 ft galvanized iron tank used for this fibre-optic hydrophone work due to the presence of strong acoustic echoes. Because the separation between the transmitting piezoelectric transducer and the receiving fibre-optic sensor is comparable to the distance between the walls of the tank and the transmitting / receiving devices, it is very difficult to gate out the echoes using pulsed – CW techniques. .

Whilst we were considering various materials which we might use to line the tank and thus absorb the energy in the acoustic echoes, the author's attention was drawn by an item on the Tomorrow's World program which was shown last December. The acoustic absorption properties of Sorbothane as demonstrated on the program, were sufficient to convince the author that it might be worthwhile to obtain a sample of Sorbothane for testing; such is the power of the media.

In order to measure the high-frequency acoustic properties of Sorbothane, we constructed two sets of piezoelectric acoustic transducers, one set resonant at 0.5 MHz and the other at 1 MHz. These transducers consisted of 2 cm diameter PXE-5 (Mullard piezoelectric ceramic) thickness-mode plates which were attached to modified N-Type electrical connectors.

Measurement of Transmission and Reflection Loss

This system is typical for ultrasonic testing of materials. A continuous-wave (CW) source is applied to a diode-bridge modulator and gated by a pulse generator. The frequency of the CW source is centered at the resonant frequency of the ultrasonic piezoelectric transducers. The pulsed-CW signal from the diode-bridge modulator is applied to one beam of a double-beam oscilloscope, and to the input of a power amplifier. This power amplifier was capable of providing a 3W CW input into a 50 Ω load. The piezoelectric transducers were not matched to 50 Ω nor was the static capacitance of each transducer tuned out. Impedance-matching would improve the dynamic range of the system, though it must be appreciated that the electrical impedance of the transducers is dependent on the acoustic load. For a water acoustic load, the real impedance of the 0.5 MHz & 1MHz transducers is calculated to be approximately 89 Ω and 22 Ω respectively, whilst their clamped capacitance is calculated to be approximately 500 pF and 1,000 pF respectively.

The acoustic signal from the transmitting transducer is passed through the sample and received by an identical transducer for transmission tests. For reflection tests the signal from the transmitting transducer is bounced off the surface of the sample and picked up by the receiving transducer.

The acoustic signal picked up by the receiving transducer is converted back into an electrical signal, which is passed through a stepped attenuator of 120 dB maximum attenuation. This attenuator was variable in 10 dB steps. The signal is then amplified and passed through a narrow-band bandpass filter to improve the signal-to-noise ratio of the signal displayed on the second beam of the oscilloscope. The bandpass filter is tuned to the transducer resonant frequency, i.e. the frequency of the RF source. The gain of the amplifier was about 40 dB.

The signal level reference, which represents zero transmission loss, was obtained by placing the faces of the transducers together and switching in sufficient attenuation to provide a convenient display on the oscilloscope. Some silicone grease was smeared on the faces of the transducers and on the Sorbothane Samples when conducting transmission tests, so as to ensure reliable acoustic contact between the surfaces.

For the transmission tests, the sample of Sorbothane was placed between the transducers and only light pressure applied, so as not to compress the Sorbothane and thus reduce its thickness. The attenuation was then reduced so as to produce a signal on the oscilloscope with approximately the same amplitude. The change in attenuation required corresponds approximately to the insertion loss of the material.

The reflections tests were conducted under water in a small fish tank (40.5 cm x 20.2 cm x 20.2 cm) by bouncing (reflecting) the acoustic energy off the surface of the samples. If the material is a good impedance-match to water then very little energy would be reflected from its surface. If in addition, the internal losses are very high, then no energy would be returned from the rear of the sample.

Experimental Results

One of the first tests carried out on Sorbothane was to measure the velocity of high-frequency acoustic bulk waves. From a knowledge of the material density p and the acoustic velocity v, we can calculate the specific acoustic impedance Z,

$$Z = \rho v \quad \text{Rayls (acoustic ohms)}$$

For water, $\rho = 10^3$ kg/m^3 and $v = 1.5 \times 10^3$ m/s. Thus Z for water is 1.5×10^6 Rayls. Since the quoted density for Sorbothane is 1.34×10^3 kg/m^3, we were hoping to measure an acoustic velocity of approximately 1.1×10^3 m/s in order that the Z for Sorbothane = 1.5×10^6 Rayls.

The acoustic velocity is determined by noting the extra delay between the pulses displayed on the oscilloscope, caused by the insertion of the Sorbothane sample.

Imagine our surprise when we found that it was impossible to get any detectable acoustic energy through the first large samples. These samples consisted of 18" x 18" sheets of Sorbothane with thicknesses of between 3/8" and 1". The earlier sample sent through the post after the initial inquiry had not at that time been tested. The large 8 mm thick samples tested were showing insertion losses in excess of 130 dB.

The limitation on the smallest signal detectable was not noise but radio frequency (RF) leakage between the transmitting and receiving transducers. Even though the transducers assemblies were completely shrouded by a grounded shell (the N-Type connector assembly) and the outer electrodes of the transducers (the acoustic contact faces) were also at electrical ground potential, some RF signal was leaking between the transmitter and receiver. This is not too surprising since the transmitter transducer was being driven with pulses corresponding to a 3W CW level and the detection electronics was very sensitive; amplifier noise being visible on the scope. At the power levels used to drive the transmitting transducer, a small voltage drop is developed across the braid of the co-ax linking the transducer to the power amplifier. It must be admitted that an electrical isolation figure of 130 dB is quite impressive and it would be very difficult to improve this figure by any significant amount.

Since the determination of specific acoustic impedance depended on our ability to measure the acoustic velocity, the high insertion loss presented some difficulty! The small disc-like blue-grey sample, which had been earlier sent in the post was then tested for the first time to see if its properties were the same as the large white samples. We were thus further surprised to find that this sample had a low acoustic loss, which we measured to be approximately 30 dB. The thickness of this sample was 1.15cm.

One thing should be made clear here and that is that the insertion loss measured includes the two reflection losses at the transducer – Sorbothane interface and the Sorbothane-transducer interface. Since there is a large acoustic impedance mismatch between the piezoelectric material and the Sorbothane, the interface losses can be quite high. However, the situation is complicated by the fact that the electrical impedance of the transducers depends on the acoustic impedance of the load. The way to eliminate the uncertainty in the measurements would be to have the acoustic signal bouncing backwards and forwards in the material several times between parallel surfaces. The ratio between successive echoes will then give the true transmission (absorption) loss. Unfortunately, we cannot do this for the high-loss Sorbothane material, even if we reduce the thickness, as the pulse resolution then becomes impaired, i.e. the delay time between echoes is too short.

For the blue-grey disc of Sorbothane we estimated from the oscilloscope display that the delay introduced by the material was approximately 12μs. Since velocity $v = s/t$, where s is the thickness of the sample and t is the time delay, we calculate that $v \approx 958$ m/s, which is not too different to the 1,100 m/s we had hoped for earlier. It must be admitted that there is some uncertainty in the calculated velocity due to the difficulties in measuring the delay time accurately. The acoustic impedance of the sample is thus 1.3×10^6 Rayls.

The power (intensity) reflection factor at an interface is given by

$$r = \left[\frac{Z_2 - Z_1}{Z_2 + Z_1}\right]^2$$

where Z_1 = acoustic impedance of first medium and Z_2 = acoustic impedance of the second (reflecting) medium. In the case of an acoustic wave traveling in water and incident on Sorbothane, $Z_1 = 1.5 \times 10^6$ and $Z_2 = 1.3 \times 10^6$. Thus the reflection factor is 0.51%. The reflection loss corresponding to this figure is 23 dB.

Note that as the frequency is reduced we can expect the acoustic impedance of Sorbothane to fall. This is because the acoustic beam width will no longer be much greater than the acoustic wavelength and Poisson's ratio will reduce the effective modulus of elasticity from that of the bulk modulus to that of Young's modulus. In plastics and rubbers these elasticity constants can be substantially different. The changes in the elasticity constants are reflected in the changes in acoustic velocity.

At high frequency the acoustic velocity v is given by,

$$v = \sqrt{\frac{B + 1.33\,G}{\rho}}$$

where B = Bulk modulus and G = shear modulus. We can make the following approximation for the acoustic velocity;

$$v = \sqrt{\frac{B}{\rho}}$$

Substituting the Sorbothane values of ρ and v into the above equation, we find that $B \approx 1.2 \times 10^9$ N/m^2. The low-frequency compressive modulus is given in the published data as $0.9 - 5.2 \times 10^6$ N/m^2.

Attempts were made to estimate the reflection losses in water directly by bouncing sound waves off the material in a small fish tank and by lining the tank with Sorbothane to observe the reduction in echo amplitudes.

The transmitting and receiving transducers were positioned on the glass bottom of the tank with their faces parallel and separated by 12.5 cm. The low-amplitude signals between the main pulses are the echoes from the glass walls of the tank and from the surface of the water. If the surface of the water was stirred by hand, the echo signals would change their amplitudes and position.

The distinct echoes after each pulse are caused by acoustic reflections between the faces of the transducers. Since the (horizontal) sweep speed is 100 us/div. and the echoes are separated by 0.8 div., the echo delay t = 160 us. This is the time taken for the acoustic signal to complete on return trip between the transducers; a total distance of s = 25cm. Since $v = s/t$, the acoustic velocity v in water is 1.56×10^3 m/s. This is in reasonable agreement with the known value of acoustic velocity in water.

The specific acoustic impedance of a material is defined for a wave at normal incidence to its surface. The answer we get at other angles can be very different, especially for a complex material such as Sorbothane, where the acoustic impedance can have both real and imaginary components. At certain angles of incidence it is possible to obtain strong reflections. It is believed that the acoustic loss for shear waves in Sorbothane is much less than for bulk waves. It was observed during transmission tests that if the material was compressed between the transducers, and the transducers angled towards each other, then it was possible to receive a strong signal.

Some acoustic tests in air have been made to ascertain the absorption characteristics of Sorbothane at lower frequencies, i.e. below 15 kHz. A loudspeaker was enclosed by two large sheets of 0.8 cm thick high-loss Sorbothane, and driven by an audio oscillator. The sound level just outside the Sorbothane enclosure was monitored with a moving-coil microphone and an oscilloscope. Having first checked the loudspeaker/microphone system for a flat frequency response up to about 10 kHz, the loudspeaker signal was then monitored over a wide frequency range with the speaker in the Sorbothane enclosure. At 1 kHz, the relative loss was about 30 dB and this rose to 35 dB at 3 kHz. At 5 kHz the loss has increased to 40 dB. The impression was obtained that the absorption of Sorbothane increases rapidly with frequency once a frequency of a few kHz is exceeded. Frequencies above 10 kHz appear to suffer severe attenuation.

During the investigations reported here, we noticed that the acoustic properties of freshly produced Sorbothane changed with time. This was somewhat disconcerting but should not present a problem if the material is properly formed and aged. A more serious problem was the lack of reproductibility in the acoustic-loss measurements with different samples of Sorbothane.

The second set of large sheets of white Sorbothane was found to have low-acoustic loss; the losses being at about that found for other synthetic rubber compounds. One sheet of this second set had a stippled (egg-crated) surface for scattering acoustic energy. A third set of eight 15cm x 15cm x 1.4cm black Sorbothane sheets was also found to be low-loss. This set had been specially graded for a range of elastic stiffness. No. 1 material was the least stiff of the samples.

Attempts were made to discover which material had the better impedance match to water by reflecting acoustic energy off the surface. Unfortunately, the uncertainty in the experimental measurements is quite high, so the differences between the material, if any, were masked. There was some indication that the softer No. 5 material reflected less energy.

Requirements for the UCL Hydrophone Test-Tank

The quantity of material required to line the UCL hydrophone test-tank is quite large. Since the dimensions of the water tank are 6' x 3½' x 3' and we wish to cover the four walls and the bottom, the surface area involved is approximately 81 sq. ft. Each 'tile' could be approximately 6" x 6" and have a basic thickness (backing) of 1". On top of this would be an egg-crated surface with 1" high peaks. The size of this egg-crating would be similar to that of actual egg-crating since we require the capability of scattering low-frequency acoustic waves, where the absorption of the material will be relatively low.

There is a further requirement for a hollow Sorbothane Cylinder to house the piezoelectric disc transducer used as the acoustic projector in the water-tank. This will prevent acoustic energy being radiated in directions other than forward. Fig. 6 illustrates the basic idea; the cylinder being about 3 or 4 inches long and having an internal diameter to produce a tight fit around the 5 cm diameter piezoelectric disc. The rear of the cylinder is closed so that no acoustic radiation occurs in the rear direction. The piezoelectric disc resonates at 100 kHz, so that a wall thickness of 1 or 2 cm should produce sufficient attenuation.

Discussion

The experimental results detailed in this report indicate that Sorbothane can have very interesting acoustic properties at high-frequencies. Optimization of these properties will require more refined measurement techniques than those detailed here. As far as the UCL requirements are concerned, it does not appear to be worthwhile to expend any further effort to minimize the reflection factor of Sorbothane in water. The present reflection factor appears sufficiently low, and anyway, perfect matching becomes somewhat academic since most of the acoustic energy incident on the walls of the tank will not be at normal incidence.

The acoustic-loss measurements have also been done at harmonics of the basic transducer frequencies, i.e. 1.5 MHz and 3 MHz. The transmission loss at 0.5 MHz, 1MHz, 1.5 MHz, and 3 MHz is greater than 130 dB. From these spot frequency measurements we can conclude that the high acoustic absorption is not due to a peculiar molecular resonance and probably rises with increasing frequency according to some power-law.

It would obviously be very useful if we can obtain an accurate figure for the acoustic attenuation. To enable us to make these measurements, we require some samples of the high-loss Sorbothane with a thickness of about 3mm and having parallel surfaces. The short distance between the transducers will prevent the accurate determination of acoustic velocity. However, the transmission loss will be much lower since the path length is shorter, and the received acoustic signal should swamp the RF leakage signal between the transducers. For instance, if the attenuation of the material is 130 dB/cm, then a 3 mm section of the material will have an attenuation of 39 dB (ignoring any interface losses). The fact that the transducers will be several times closer will increase the RF leakage, but by only a few dB, whilst the acoustic signal will increase by 91 dB (again, ignoring the fixed interface losses).

The other obvious attenuation measurements that could be made with the thicker sheets of Sorbothane is that at lower frequencies, i.e. at frequencies between 1 kHz and 500 kHz. We could then characterize the acoustic loss over a wide frequency range and also separate the interface losses from that of the internal absorption.

It should not require the author to point out the obvious commercial applications for a material having both a good impedance match to water and an incredibly high acoustic absorption. These applications include, of course, the present requirement for an anechoic lining in hydrophone test-tanks. An obvious military application for Sorbothane would be to reduce the sonar cross-section of a vessel, such as a submarine, by covering the vessel with the material. A submarine might be rendered acoustically invisible by such means. Sorbothane would also reduce the acoustic noise generated from within the vessel. In an industrial environment, the material might be used to suppress high-frequency noise pollution.

Conclusions

The high-frequency acoustic properties of Sorbothane, make it an unusual material. The internal acoustic losses appear to rise rapidly above 10 kHz and at 500 kHz reach a value of greater than 130 dB/cm. The specific acoustic impedance of Sorbothane appears to be very similar to that of water and the acoustic velocity in the lower-loss material is about 1 km/s at frequencies in excess of 500 kHz. Sorbothane should make a very effective anechoic lining for hydrophone test-tanks.

Reference

KINSLER, L.E. and FREY, A.R.: "Fundamentals of Acoustics", 2nd Edition, John Wiley & Sons, 1962.

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