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COATING FOR AN UNDERWATER ACTIVE ACOUSTIC ATTENUATION CONTROL SYSTEM

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Abstract - A multilayer encapsulated coating has been developed for underwater acoustic attenuation purposes. This coating provides an option for electronically activating encapsulated piezoelectric devices to increase the coatings passive sound attenuation performance through active control methods. These methods include the ability to sense the incident and reflected acoustic pressure field and produce a counter destructive interference acoustic pressure wave for sound cancellation. Experimental results are presented from measurements conducted in a water filled pulse tube for normally incident acoustic waves.

1 - INTRODUCTION

The traditional solution to the problem of underwater sound attenuation has been through the use of highly damped air - rubber composite panels placed over an object that one wishes to acoustically camouflage. The recent introduction of advanced piezoelectric materials now offer the designer new techniques for solution of this acoustic problem. The encapsulation of these piezoelectric materials into a host polymer allows the option of both passive and active control methods. The passive methods are the mechanical dissipation properties introduced by the presence of the composite coating. These dissipation losses are handed over an extended frequency range while the active methods are used for attenuation over limited frequency bands or tonals. Although the passive attenuation component of this coating is not of the extent of the traditional air - rubber panels, the multilayer coating offers other distinct advantages. These include independence of hydrostatic pressure and, more importantly, the active control component.

Active control techniques are utilized in applications where specific tonals or frequency bandwidths require increased sound attenuation beyond that of the passive component. Active techniques have recently found use in air-borne applications, such as noise reduction in air ducts /1,2,3/. Two in air applied methods include the cancellation of a reflected acoustic wave in both an acoustically terminated air tube /4/ and from a wall /5/. This reflection cancellation was accomplished by setting up a sound wave that would add with the reflected wave to cause the destructive interference condition at the termination wall. Similar techniques have been demonstrated in a water filled pulse tube by using dual hydrophones of piezoelectric ceramic /6/. Active acoustic absorbing systems typically begin with a sensing device to detect the impressed acoustic field and output an electrical signal in terms of this field /7/. The voltage output of the sensors is input through a control circuit and into an actuating device such that the actuator output causes a destructive interference condition with the acoustic reflection. The underwater principals used in this ceramic hydrophone case may be improved by encapsulating piezoelectric hydrophones inside the coating to replace the piezoceramic hydrophones. The actuator may also be composed of a piezocomposite structure and encapsulated in the same host matrix. Furthermore, a recent analytical model has also suggested the cancellation of both the reflected and transmitted acoustic wave by use of a bilaminate actuator design /8/. The advantage gained by using this coating arrangement is the fact that the complete sensor and actuator devices are now enclosed in one thin multilayered coating package. A conceptual drawing of the coating over an object is presented in Figure 1. This coating package may be applied over the underwater object to cancel with the resultant acoustic field upon the interaction of the incident wave with the object.
Fig. 1 - Conceptual drawing of underwater acoustic attenuation coating over object to be covered for acoustic camouflage.

2 - THE COHERENT WAVE FIELD

To understand which acoustic pressure wave in the coherent field is associated with the reflected wave, it is necessary to separate the incident and reflected acoustic waves. To accomplish this, a dual sensor arrangement can be used as shown in Figure 2 for the case of an acoustic pulse tube with two piezoceramic spherical hydrophones, A and B, in front of an actuator. For detection of both the incident (P⁺) and reflected (P⁻) acoustic wave pressures it is necessary to output the voltages of the two sensors, V_A and V_B respectively, as caused by the coherent pressure field. The two sensors are separated by a distance d.

Fig. 2 - Experimental setup for pulse tube measurements using dual piezoceramic sensors scheme.

The pressure detected at sensors A and B may be expressed as a superposition of both the incident and reflected field, hence,

\[ V_A = S [ P^+ + P^- ] \]
\[ V_B = S [ P^+ e^{jkd} + P^- e^{-jkd} ] \]

where S is the acoustic sensitivity output of the matched hydrophones. The output of hydrophone B is first input into an electronic phase shifter to account for the separation distance d and then subtracted from the signal of hydrophone A through a differential amplifier, hence,

\[ V_S = V_A - V_B e^{jkd} \]
where in (6) the voltage output of the differential amplifier \( (V_S) \) is related to the incident pressure \( (P^+) \). It should also be noted that the separation distance between the hydrophones, \( d \), cannot be an integer of \( \pi \), hence \( kd \neq \pi n \). This condition is the factor that must be used to determine the frequency band of operation. The output voltage of the differential amplifier, \( V_S \), is now input into a second electronic phase shifter that accounts for the distance between the sensor B and the front face of the actuator. The output of this electronic component is a signal of opposite phase of the reflected wave and thus input through a power amplifier into the actuator. The actuator will then produce an acoustic pressure wave of equal amplitude and opposite phase to that of the reflected acoustic pressure wave at the surface of the actuator. The field conditions are therefore set for destructive interference to occur between the reflected acoustic wave and the actuator driven wave.

3 - SENSOR DESIGN

To experimentally evaluate the concept of using a dual sensor scheme for characterization of the coherent wave field, the two piezoceramic hydrophones shown in Figure 2 were used. A comparison of these results were made with two encapsulated sheets of polyvinylidene fluoride (PVDF), which is a piezoelectric polymer. This material was selected for several reasons such as the fact that its characteristic impedance is on the order of the fluid medium, therefore indicating that the incident acoustic wave will pass through the sensors with minimal reflection. Other advantages include superior uniformity between sensors of these materials compared with piezoceramics, thus allowing improved subtraction of their outputs at the differential amplifier. Additionally, because the piezoelectric polymer has greater damped mechanical resonances, the frequency range of operation will be broader and their plate geometry will easily accommodate a coating type of application.

The piezoceramic spherical hydrophones shown in Figure 2 and the PVDF sensors were each experimentally measured with a sinusoidal drive signal at a frequency of 5.40 kHz. A comparison of the attenuation of the reflection coefficient of the first echo as a function of frequency and amplitude is graphed in Figure 3. This comparison plot shows that the PVDF sensors offer an increased bandwidth of coverage which is due partly to the addition of the passive component associated with the polymer encapsulant arrangement.
4 - ACTUATOR DESIGN

The desire for selection of a suitable actuator is for a material that will meet the design requirements and be as thin as possible. Since this coating is to be used at low frequencies, the thickness of the actuator as a function of frequency and velocity displacement must be taken into account. In the case of low frequency and low incident acoustic pressure, the use of a 0-3 piezocomposite is possible. Experimental results in the acoustic pulse tube have demonstrated attenuation of the first reflection in excess of 25 dB at 5 kHz. At higher incident acoustic pressures, additional displacement is required. To accomplish this, 1-3 piezocomposite materials may be designed for low frequency resonance where this resonance should be designed to be either in or near the frequency band of interest for optimum performance. Experimental results have shown that the necessary volume concentration for these composites is on the order of 30 percent.

In addition to canceling the acoustic reflection, the use of a bilaminate actuator design can also be used for attenuating both the acoustic reflection and the transmission into the underwater object, regardless of the objects interior medium. A full analysis of this design is presented in /8/.

5 - CONCLUSIONS

A multilayer coating for the attenuation of underwater acoustic pressure waves through active electronic techniques has been developed. The work discussed here is only for normally incident acoustic waves and is over a limited frequency range. Further extension of this work through improvements in the electronics control system could yield both off normal attenuation and broader frequency responses. Regardless of these electronic improvements, the multilayered coating presented here is adaptable for use with a variety of electronic schemes. The coating that has been developed here offers many new possibilities for solution in the problem of underwater sound attenuation.

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