Determination of efficiency of anechoic or decoupling hull coatings using water tank acoustic measurements

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External anechoic and decoupling hull coatings are used on ships or submarines to reduce underwater acoustic target strength and radiated noise, respectively. Measurement of test panels in a water tank gives only the reflection and transmission coefficients in free field, with respects to frequency. It is shown using simple models that anechoic and decoupling efficiencies can be derived, providing appropriate modulus and phase measurement of the coefficients. Additionnally, the influence of a non-rigid elastic backing plate can be simulated without additional measurement. That information is of particular interest for the naval architects and specialists involved in design. In this paper, the theoretical formulation of the problem will be presented, with a discussion of the influence of measurement errors. The method is then applied experimentally to a test case. Results confirm the practical validity of the method.

1 Introduction

Passive and active sonar systems are commonly used to detect ships or submarines using acoustic wave propagation and processing. More details about the context can be found for example in [1]. In order to mitigate the risk of being detected by adverse systems, it is necessary to reduce underwater radiated noise (for a passive sonar threat) and/or acoustic target strength (for an active sonar threat).

One of the most efficient technological solutions to achieve this goal is the use of hull external acoustic coatings, mainly of two types:

- Decoupling coatings consisting in surrounding the radiating parts of the hull by a layer of compliant material. The role of a decoupling coating is to reduce the radiation factor, or radiation efficiency of the hull.

- Anechoic coatings, whose role is to reduce acoustic reflection from the hull, by absorbing incoming waves.

On the technological aspect, these coatings generally consist in viscoelastic layers, a few centimetres thick, with some repartition of voids and other inclusions in the matrix.

In order to optimize ship or submarine design regarding acoustic discretion and stealth, it is necessary to assess the efficiency of the coatings, not only the intrinsic properties of the material, but integrated on the hull. A method able to determine these performances, based on a post-processing of standard acoustic measurements of test panels in a water tank has already been presented in a previous paper [2].

The purpose of the present paper is to present additional results regarding the sensitivity of the method with respect to measurement errors, and its validation using experimental results obtained on a test sample.

2 Principle of the method

2.1 Acoustic measurements of a test panel in a water tank

A test panel of the coating under test is placed in a water tank (figure 1). Acoustic waves are generated in water using a transducer, generally in the form of sinusoidal signals with a time window. Hydrophones are placed on both sides of the test panels, in near field, to measure the acoustic pressure.

A reference measurement without panel is done, then a measurement with test panel. Comparison allows determining reflection and transmission coefficients (both amplitude and phase) along frequency, by varying the frequency of the emitted signal.

These experiments can be performed either in an open water tank, either in pressure water tanks. In the latter case, the facility allows to perform the measurement at different static pressures, allowing simulating the effect of water depth on the acoustic performance of the test sample. Some equipment and techniques are presented for example in [4].

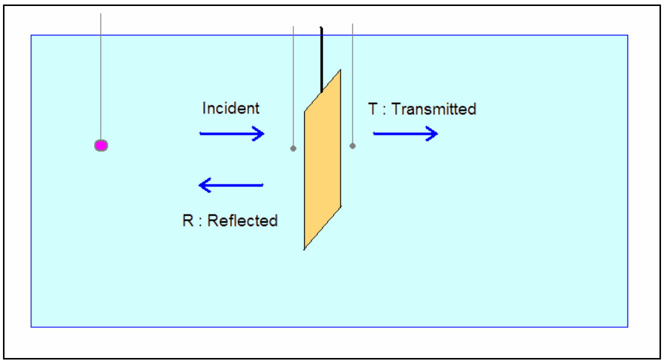

Figure 1: Test panel measurement in a water tank

2.2 Assessing the efficiency of an acoustic coating on a ship hull

The method presented above allows determining only the transmission coefficient T or the reflection coefficient R of the test panel in free field, i.e. with water on both sides, but not the acoustic efficiency of the coating integrated on a ship hull.

The need is to assess the decoupling and anechoic efficienies of a coating integrated on a pressure hull (i.e. with air inside), as shown on figure 2. In that case, total reflection occurs if the hull is not coated, and in a simplified approach, the hull can be assumed to be rigid.

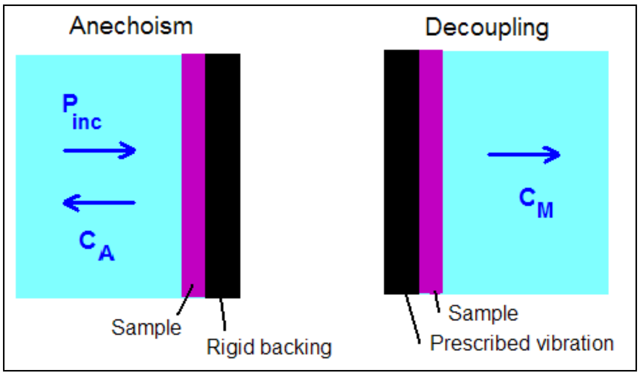

Figure 2: Definition of anechoism and decoupling coefficients

Another case of practical interest occurs when the coating is integrated on a thinner structure, like external casings or frameworks on submarines (figure 3). The backing structure is typically made of steel or GRP (Glass reinforced plastic). The presence of this backing can modify significantly the acoustic performance of the coating.

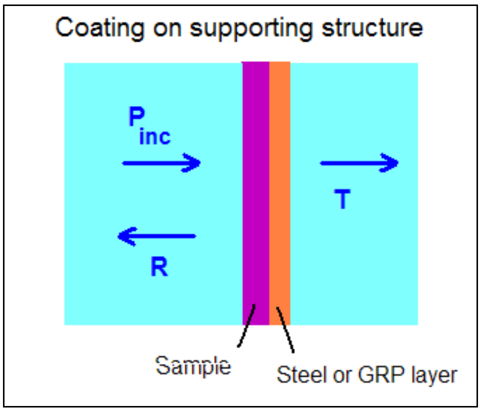

Figure 3: Case of an acoustic coating on a backing plate

As discussed previously [2]. There is no easy method or facility to determine these parameters through direct measurement. The method proposed here consists in obtaining the desired data through a post-processing of the free field measurement of a test panel in a water tank.

The first step is to determine, for a given frequency, the complex-valued reflection and transmission of the test panel for the two directions of incidence, respectively R_1 and T_1, and R_2 and T_2. Here, we assume normal incidence. In the case of a homogeneous or a symmetric test panel, only one experiment is necessary, as T_2 equals T_1 and R_2 equals R_1.

A transfer matrix model, similar to those introduced in [3], relating acoustic pressure "p" and displacement "u" on both sides of the panel is given by:

$$\begin{bmatrix} p_2 \\ u_2 \end{bmatrix} = [M_C]\begin{bmatrix} p_1 \\ u_1 \end{bmatrix}, \text{ with } [M_C] = \begin{bmatrix} \alpha & \beta \\ \beta' & \alpha' \end{bmatrix},$$

$$\alpha = \frac{1 + T_1T_2 - R_1R_2 - R_1 + R_2}{2.T_2},$$

$$\beta = -i\rho c\omega \frac{1 - T_1T_2 + R_1R_2 + R_1 + R_2}{2.T_2},$$

$$\beta' = \frac{i}{\rho c\omega}.\frac{1 - T_1T_2 + R_1R_2 - R_1 - R_2}{2.T_2},$$

$$\alpha' = \frac{1 + T_1T_2 - R_1R_2 + R_1 - R_2}{2.T_2}.$$

where ρ, c, are water volumetric mass and speed of sound, respectively, and ω circular frequency.

In a second step, decoupling and anechoism coefficient can be determined, without additional experiment, by:

$$C_A = \frac{\alpha' + i\rho c\omega\beta'}{\alpha - i\rho c\omega\beta'} = R_1 + \frac{T_1.T_2}{1 - R_2} \quad (1a)$$

$$C_M = \frac{\alpha.\alpha' - \beta.\beta'}{\alpha - i\rho c\omega\beta'} = \frac{T_1}{1 - R_1} \quad (1b)$$

The total reflection coefficient R_{tot} and transmission coefficient T_{tot} of an acoustic coating on backing plate can also be simulated easily, using the following expressions:

$$[M_{TOT}] = [M_S][M_C] = \begin{bmatrix} \alpha_{TOT} & \beta_{TOT} \\ \beta'_{TOT} & \alpha'_{TOT} \end{bmatrix}, \quad \text{with:}$$

$$[M_S] = \begin{bmatrix} \alpha_S & \beta_S \\ \beta'_S & \alpha'_S \end{bmatrix} = \begin{bmatrix} \cos(k_S h_S) & \rho_S c_S \omega.\sin(k_S h_S) \\ -\dfrac{\sin(k_S h_S)}{\rho_S c_S \omega} & \cos(k_S h_S) \end{bmatrix}.$$

$$R_{TOT} = \frac{\alpha'_{TOT} - \alpha_{TOT} + i.\left(\dfrac{\beta_{TOT}}{\rho c\omega} + \rho c\omega\beta'_{TOT}\right)}{\alpha'_{TOT} + \alpha_{TOT} + i.\left(\dfrac{\beta_{TOT}}{\rho c\omega} - \rho c\omega\beta'_{TOT}\right)}, \quad (2a)$$

$$T_{TOT} = \frac{2.(\alpha_{TOT}\alpha'_{TOT} - \beta_{TOT}\beta'_{TOT})}{\alpha'_{TOT} + \alpha_{TOT} + i.\left(\dfrac{\beta_{TOT}}{\rho c\omega} - \rho c\omega\beta'_{TOT}\right)}. \quad (2b)$$

Here, c_s denotes the longitudinal celerity in the baking plate, with k_s the corresponding wavenumber, h_s its thickness, ρ_s its volumetric mass.

2.3 Influence of measurement errors

A topic of concern is the robustness of the process used to derive the decoupling and anechoism coefficients from the free field measurements. As a matter of facts, some measurement errors arise from acoustic water tank measurement, as it is the case for any experimental procedure. For that purpose, some simulations have been done by introducing artificially an error on theoretical data for some test cases, the result being the comparison between exact (theoretical) decoupling and anechoism coefficient, and the same data after having propagated the error through Eq. (1).

A first test case corresponding to a bi-function coating is shown on figure 4. Frequency scale, in the kHz range, is not shown for confidentiality reasons.

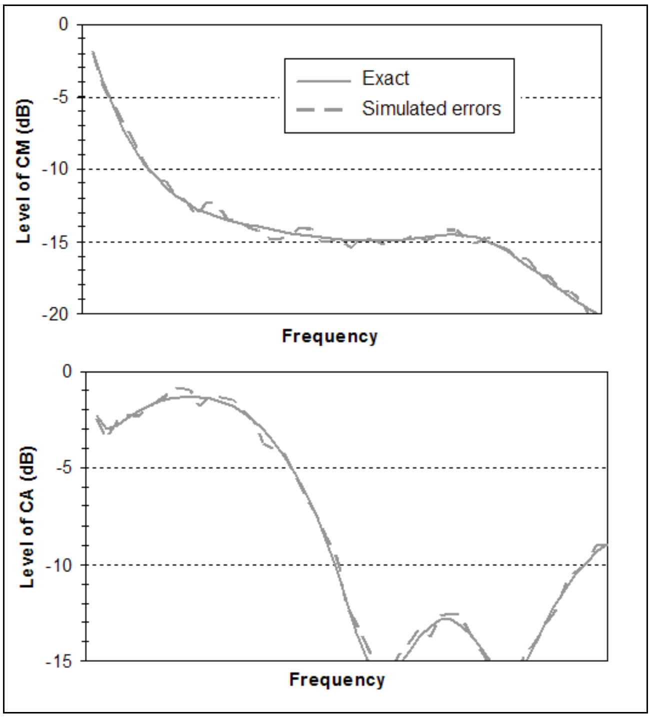

Figure 4: Simulation of measurement error on a bifunction test material

The error introduced in the R and T data is 10% in modulus and random in phase. The results show that in this case, the output error remains low, not larger than for the input data.

A second example, shown on figure 5, refers to a steel plate immersed in water. Obviously, a steel plate is not adequate to produce a decoupling or anechoic effect: theoretically, the anechoic effect is null (i.e. 0dB) and the radiated pressure increases slightly (i.e. positive decoupling coefficient in dB).

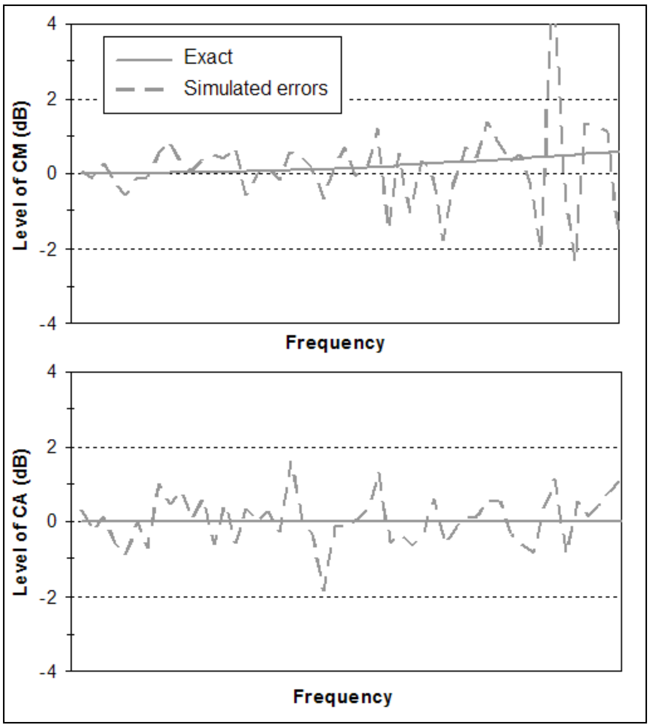

Figure 5: Simulation of measurement error on a steel plate

In this case, we see that the measurement error is significantly increased by the post processing. This is not surprising, because the reflection coefficient of a steel plate is close to 1, and of the division by ($1-R_1$) or ($1-R_2$) in Eq. (1).

In summary, the method is robust for the cases of practical interest: test panels with significant anechoic or decoupling performance. The method does not work only if the reflection coefficient is close to one with phase close to 0°, corresponding to a hard reflector.

3 Validation with experimental data

The method presented in § 2.2 is now applied on experimental data. The test panel considered here is non-symmetric and is expected to exhibit both anechoic and decoupling efficiency.

3.1 Input data

The input data, figures 6 and 7, consists in free-field transmission and reflection coefficients along frequency, for both directions of incident wave. Both modulus (or level in dB) and phase have to be measured, the panel being non-symmetric. Here, the phase is referenced to the incident wave, with implicit time dependence exp(iωt). It should be noted that the phase must be carefully measured and referenced. We can see that for this test panel, reflection coefficient for incoming direction 2 is close to 0 dB and 180° phase, which is characteristic of a soft reflector acoustic behavior.

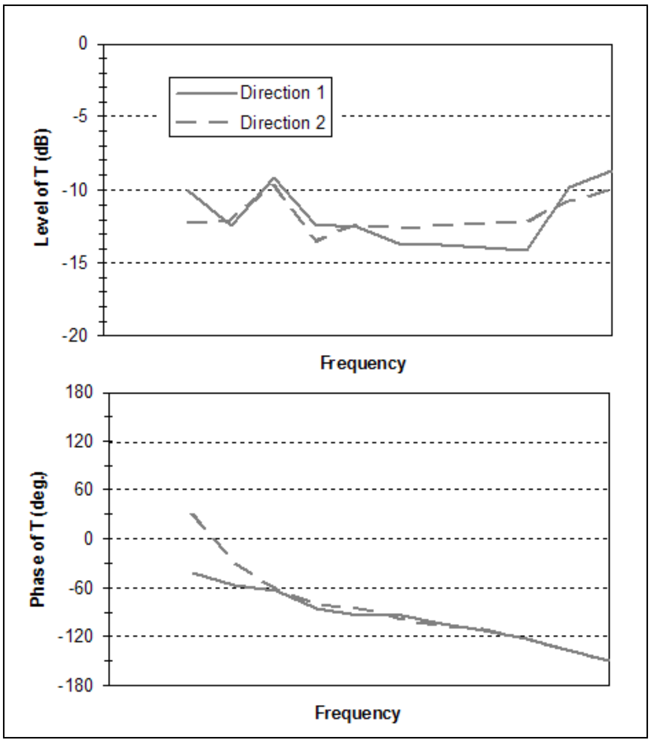

Figure 6: Transmission coefficient of test panel

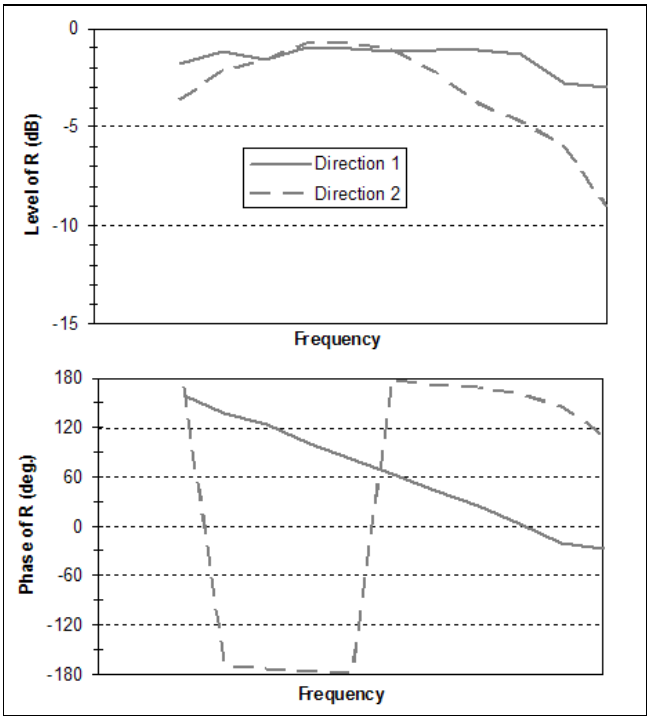

Figure 7: Reflection coefficient of test panel

If we compare results for directions 1 and 2, the measured values are quite similar for the transmission coefficient, but differ for the reflection coefficient, both in phase and modulus.

3.2 Decoupling and anechoism coefficients

Figure 8 shows the results for the decoupling and the anechoism coefficients, after applying Eq. (1).

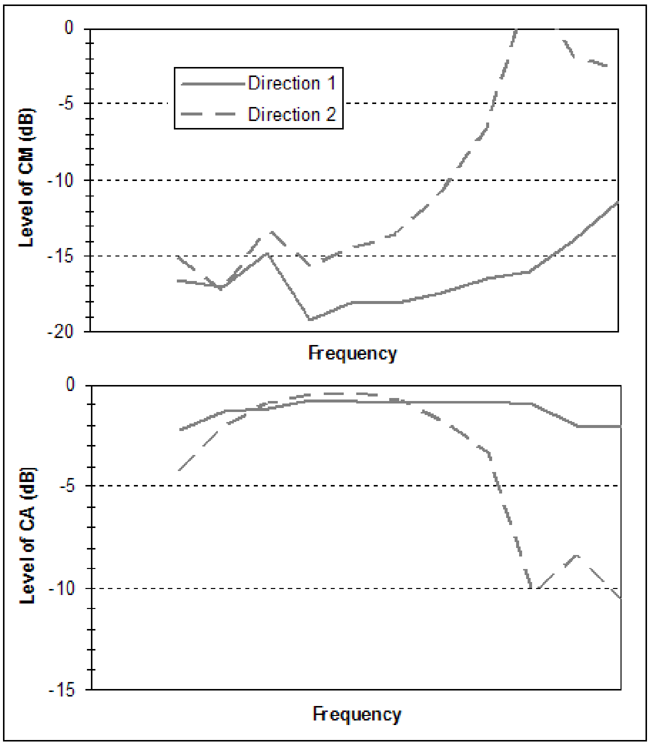

Figure 8: Decoupling and anechoism coefficients of test panel

Results show that this test panel has good decoupling performance if excited from direction 1, but exhibits a resonance in the high frequency range if excited from direction 2. Considering anechoic coefficient, we confirm the soft reflector character when excited from direction 1, and on the other hand, a good anechoic efficient can be obtained in the high frequency range when excited from the other direction.

Then, as far as a non-symmetric panel is concerned, the direction of incoming wave with respect to the panel side is very important.

3.3 Influence of a backing plate

Additionally, the influence of a steel backing plate on the previous test sample is studied.

Using the same input data, Eq. (2) is used to simulate the acoustical effect of the backing plate on the reflection and transmission coefficient of the whole.

Results are shown on figure 9, with comparison of direct measurement from another experiment, where the backing plate was actually glued on the sample and the assembly measured again in a water tank.

The results are consistent one to each other, except may be for high frequency points on the transmission coefficient.

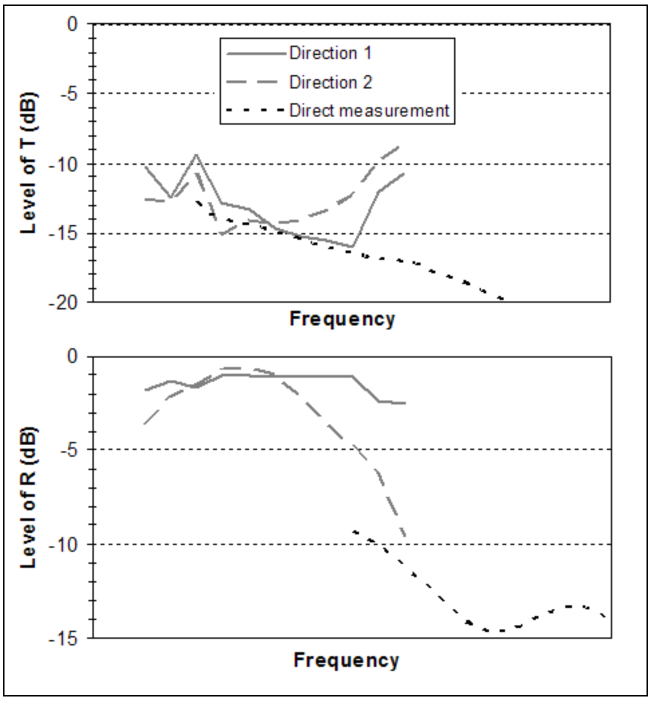

Figure 9: Transmission and reflection coefficients of test panel on a steel backing plate

4 Conclusion

A method has been presented to characterize underwater acoustic coatings for decoupling and anechoic efficiencies, as well as the influence of backing plates. As input data, the method uses standard free-field measurements of a test panel in water tank facilities.

It has been shown in this paper that the method is robust with respects to measurement errors, as far as relevant materials are considered. Application of the method on experimental data from a test sample has shown consistent results, thus proving its practical use.

References

[1] R.J. Urick, *Principles of Underwater Sound – 3rd edition*, McGraw-Hill Ed. (1983)

[2] C. Audoly , *"Acoustic characterisation of anechoic or decoupling coatings taking into account the supporting hull",* RINA Warship 2011 conference, Naval Submarines and UUVs, 29 – 30 June, 2011, Bath, UK

[3] M. Bruneau, C. Potel, BRUNEAU & M., POTEL, C. *Materials and Acoustics Handbook*, ISTE, Wiley Ed., 2009

[4] V.F. Humphrey, S.P. Robinson, J.D. Smith, M. J. Martin, G.A. Beamiss, G. Hayman, N.L. Carroll, *"Acoustic characterization of panel materials under simulated ocean condition using a parametric array source"*, J. Acoust. Soc. Am Vol. 124, 2008