C. R. Mecanique 343 (2015) 645–655

Contents lists available at ScienceDirect

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Acoustic metamaterials and phononic crystals

Acoustic coatings for maritime systems applications using resonant phenomena

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ARTICLE INFO

Article history:
Received 8 April 2015
Accepted 9 July 2015
Available online 29 July 2015

Keywords:
Acoustic coatings
Underwater acoustics
Resonant phenomena

ABSTRACT

There is a great interest in the availability of acoustic coatings for maritime systems applications, in particular for the reduction of radiated noise in water. The purpose of this paper is to give an overview of recent results regarding the design of such materials, which are classically of two main types: the micro-inclusion technology and the Alberich-type coating. In both cases, resonances of inclusions are exploited. Here, the concepts are extended to configurations with several layers of periodic arrangements of soft and rigid inclusions. The analysis is done using the finite-element technique. The results show a wide variety of acoustical phenomena, allowing us to customise the design according to different applications.

1. Introduction

1.1. Acoustic coatings in maritime applications

In the context of naval operations, passive and active sonar systems are commonly used to detect ships or submarines using acoustic wave propagation and signal processing. One of the most efficient technological solutions to reduce the threats is the use of hull external acoustic coatings, mainly of two types [1], as shown in Fig. 1:

- 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.

We must also stress that there is currently an increasing concern about the protection of marine life regarding underwater sound emitted by human activity at sea. Indeed, the Maritime Strategy Framework Directive adopted in 2008 by the European Union [2] requires that the member states ensure a good environmental status in European maritime areas, including the introduction of energy, underwater noise being one of these. As a consequence, the reduction of underwater

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http://dx.doi.org/10.1016/j.crme.2015.07.004

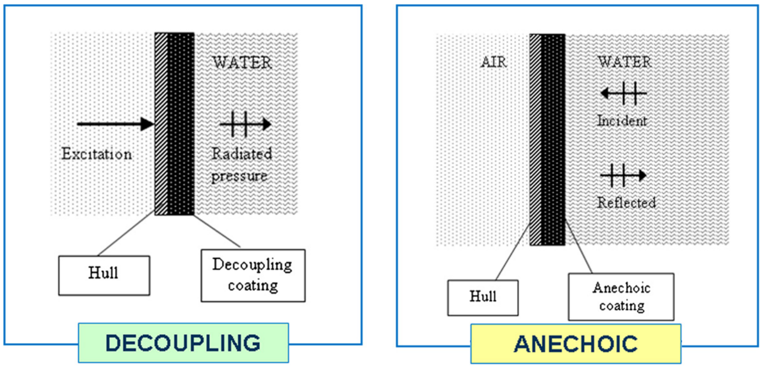

Fig. 1. (Colour online.) The two main types of acoustic hull coatings: (on the left) decoupling coating and (on the right) anechoic coating.

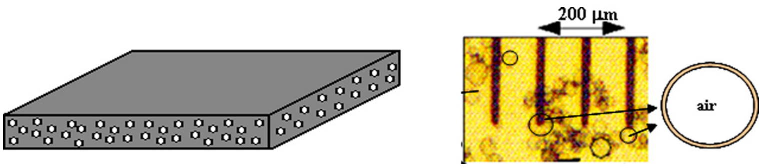

Fig. 2. (Colour online.) (On the left.) Schematic view of a viscoelastic slab incorporating inclusions, corresponding to the micro-inclusion technology. (On the right.) Microscope view of the actual inclusions in a slab (reproduced from [3]).

noise from any civilian maritime system, such as commercial ships, marine renewable energy systems, or more generally the exploitation of ocean resources, and the availability of related technical solutions is of increasing interest.

1.2. Frequency range of interest

Underwater acoustics cover a wide frequency range of interest. For example, the characterisation of sea bottom or the detection of objects on the sea floor generally involves systems operating with frequencies from a few kHz up to several hundreds of kHz, whereas long-range detection sonars use lower frequencies. The size order corresponding to the wavelength is that of the centimetre. Thus, the design or the choice of an acoustic coating will depend on the application and of the frequency range of interest.

1.3. Technology

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.

The technology can be split into two main types: micro-inclusion technology consisting of micro-voids and/or other very small micro-inclusions (<1 mm) randomly distributed in a viscoelastic matrix, and macro-inclusion technology, which uses inclusions still smaller than the typical wavelength but on the same order of size (cm). The latter can itself be split into two categories:

- macro-inclusions randomly distributed in a viscoelastic matrix, which is the extension of the micro-inclusion technology where local resonances of the inclusions are observed in the frequency range of interest,
- Alberich-type coatings, consisting generally of macro-inclusions arranged periodically in a viscoelastic matrix. In this case, additional phenomena occur in relationship with the periodic arrangement of inclusions.

These different technologies can be used for the realisation of both absorbing and decoupling coatings, depending on the design.

In the micro-inclusion technology, the absorption or attenuation is obtained by incorporating micro-voids, generally in the form of micro-balloons with soft walls (Fig. 2). Besides, in order to obtain the desired performance for the coating, several layers of viscoelastic slabs with different properties or volume ratio of inclusions can be used. The presence of air inclusions, if any, renders the material dependent on hydrostatic pressure, which has to be taken into account for underwater applications [3,4]. In most current realisations, these inclusions are microscopic, but it would be possible to realise materials with larger inclusion sizes, allowing one to obtain acoustical effects at lower frequencies.

Alberich-type coatings generally use a periodic arrangement of inclusions in a viscoelastic matrix, either in two or three dimensions, as shown in Fig. 3. In most current realisations, there is only one layer of inclusions. However, it is possible to realise coatings formed with several layers. Some examples will be given in Section 3.