1J3-3

Symmetric and asymmetric spectra of acoustic waves resonantly transmitted through a slab in a fluid
流体中のスラブを共鳴透過する音響波の対称および非対称スペクトル

Seiji Mizuno† (Grad. School of Eng., Hokkaido Univ.)
水野誠司 (北大工)

1. Introduction

Recently, a class of sonic crystals with locally resonant structural units (e.g. a solid core material with relatively high density and a coating of elastically soft material) has attracted much attention [1, 2]. These crystals exhibit frequency gaps with lattice constants considerably smaller than the relevant sonic wave length. Very recently, as simple examples of such sonic crystals, one-dimensional phononic crystals consisting of solid and fluid layers has been studied [3, 4]. In addition, resonant transmission related to the Fano effect [5] has been suggested for these systems.

For phonons propagating through a single layer immersed in fluid, we derived an explicit expression for the Fano parameter and studied Fano resonances for a Plexiglas layer in water [6].

To understand the Fano resonance in such systems broadly, in the present proceedings, we consider a metallic slab in a fluid as an example of a system with a large acoustic mismatch between the fluid and solid. We examine symmetric and asymmetric transmission spectra characteristic of this system.

2. Method of Calculation

The calculation method we used is based on the transfer matrix method. First, the velocity potential is calculated by solving the Euler equation for the liquid layer, and the velocity and the stress fields are obtained. For the solid layer, the displacement is calculated by solving the elastic equation, and the velocity and stress fields are obtained. By imposing boundary conditions such that the shear stress at the interface is zero and the velocity and stress components normal to the interface are continuous at the interfaces, the transmission coefficient and the reflection coefficient are determined.

3. Numerical results and discussions

As a numerical example, in this study we examine an Al slab immersed in water. First, we consider a case where an elastic wave is incident perpendicularly to the interface from the fluid side. The calculated transmission spectrum is shown in Fig. 1(a). In this calculation, parameters we used are as follows: ρ = 2.70 g/cm³, c_t = 3.15 km/s, and c_ℓ = 6.45 km/s for Al; ρ = 1.00 g/cm³, c_ℓ = 1.49 km/s for water, where ρ is the mass density and c_ℓ and c_t are the phase velocities for longitudinal and transverse waves, respectively.

The incident longitudinal acoustic wave excites only the longitudinal acoustic wave in the metal because of symmetry of the system. Since the acoustic mismatch between the fluid and metal is large, most of the acoustic waves are reflected. The longitudinal acoustic waves excited in the metal are mostly reflected at the second interface. As a result, the transmittance is generally a small value. However, when the wavelength of the incident elastic wave matches the thickness of the slab, resonant transmission occurs. This resonance frequency is given as an integral multiple of $\omega_l = \pi c_l / d$, where d is the thickness of the slab. For example, $\omega_l = 20.3$ GHz for d = 1 mm.

In Fig. 1(a), resonance peaks appear at regular intervals. These peaks have symmetrical profiles expressed by Lorentz function. The transmittance value at the resonance frequency is

†e-mail address: mizuno@eng.hokudai.ac.jp

exactly unity in the symmetric system we considered.

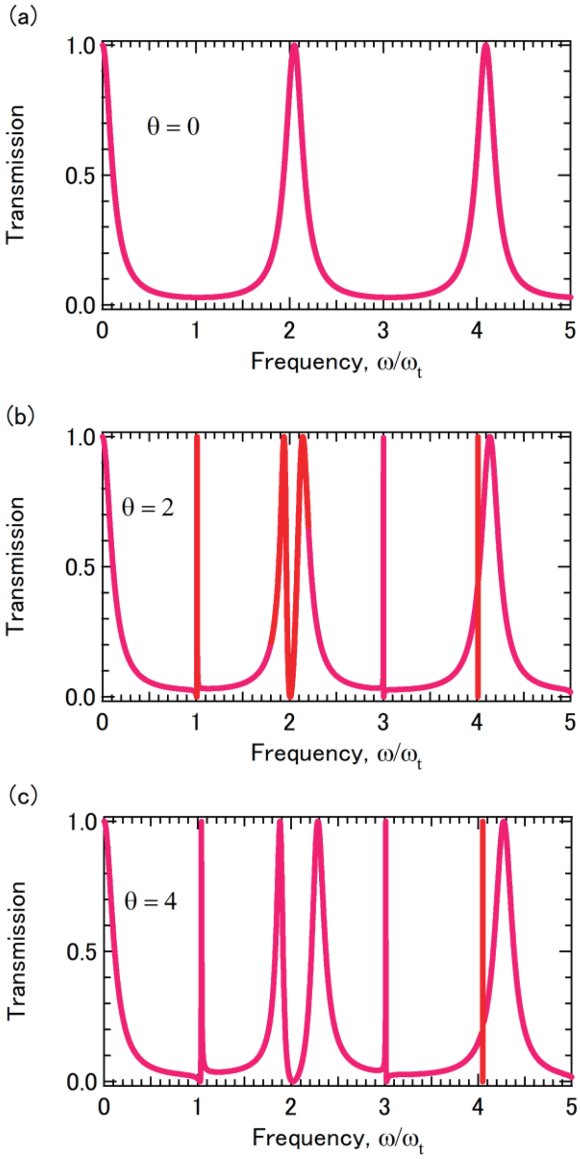

Fig. 1 Transmittance of elastic waves propagating through an Al slab in fluid. The frequency is normalized with $\omega_t = \pi c_t / d$, where d is the thickness of the slab.

Next, we consider the case where an elastic wave is incident on the interface at a slight angle. Figure 1(b) and (c) shows the transmission spectra calculated for incident angles of 2 and 4 degrees. In addition to the symmetric peaks, asymmetric peaks appear at integral multiples of $\omega_t = \pi c_t / d$, which is the frequency when the wavelength of the transverse wave matches the thickness of the slab. For example, $\omega_t = 9.9$ GHz for d = 1 mm.

These asymmetric resonance peaks are caused by the Fano effect described below. Longitudinal acoustic waves that are obliquely incident on the interface from the fluid are mostly reflected as longitudinal waves due to a large acoustic mismatch between the fluid and solid, but some are transmitted as longitudinal and also transverse waves in the solid slab.

Some of these longitudinal and transverse acoustic waves are transmitted to the fluid as longitudinal waves at the next interface, while others are reflected as longitudinal and transverse acoustic waves. These reflection rates are also large due to large acoustic mismatches between Al and water. Therefore, this reflection with mode conversion is repeated many times within the Al slab. In particular, the transverse elastic wave cannot be transmitted to the fluid region, and thus repeats reflection in the Al slab for a long time. This characteristic reflection and transmission process result in destructive and constructive interference of elastic waves. This leads to Fano resonance in which the minimum value of zero transmittance and the maximum value of transmittance 1 appear very close to each other. In the case of the present system, the two resonance frequencies ω_l and $2\omega_t$ are so close that the lowest Lorentz peak splits into two peaks, showing an anti-resonant dip between them.

Asymmetric resonance peaks can be well explained using the Fano formula. Based on the Fano formula, the asymmetric profile presented in the present paper will be discussed in detail elsewhere.

References

1. Z. Liu, X. Zhang, Y. Mao, Y. Y. Zhu, Z. Yang, C. T. Chan, and P. Sheng, Science **289**(5485), 1734, 213 (2000).
2. N. Fang, D. Xi, J. Xu, M. Ambati, W. Srituravanich, C. Sun and X. Zhang, Nat. Mater. **5**, 452 (2006).
3. S. Mizuno, Jpn. J. Appl. Phys. **55**, 017302 (2016).
4. I. Quotane, E. H. El Boudouti, and D-R. Bahram, Phys. Rev. B. **97**, 024304 (2018).
5. U. Fano, Phys. Rev. **124**, 1866 (1961).
6. S. Mizuno, Appl. Phys. Express**.** **12**, 035504 (2019).