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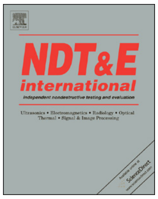

Detection of a straight groove in a metal plate by acoustic scattering in water with applications to marine current turbines

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ABSTRACT

The developed method is based on acoustic underwater scattering measurements and can be applied to characterize a defect in a blade of a marine current turbine. To simplify the study, the blade is replaced by a rectangular plate immersed in water having a groove opening out. The measurements are made on horizontal plane perpendicular to the long axis of the stainless steel plate. The frequency range of signal is between 50 and 400 kHz. The transducer is remote from the plate. The measurements are recorded on 360° with a 1° step. The experimental trajectories of the scattering signals are compared to the trajectories calculated from the group velocities of Lamb waves A and S_0. Spectra give also an information on groove position. The present study is the first step toward remote monitoring of blades on a marine current turbine.

1. Introduction

The monitoring and maintenance of immersed structures is an important challenge for the development of reliable equipments used for marine energy like stream turbines. In this context, health monitoring systems based on ultrasonic waves present numerous advantages in comparison with other methods, because such systems are highly sensitive to surface damages and can be used for remote inspections as long as the incident and radiated waves propagate over significant distances in water.

A number of studies on the acoustic scattering from simple objects immersed in water: plates, cylinders, cylindrical shells, spheres or spheroids, have already been published [1–7]. The relationship between the scattering signals and the propagating of guided waves, in these objects, has been shown [8]. In the case of plates immersed in water, the symmetric or antisymmetric Lamb waves influenced by the fluid are taken into account to explain the mechanism of scattering [9,10]. In finite length plates immersed in a fluid, quasi-Lamb waves are generated at a critical angle, at the extremities or at defects such as cracks, imperfections due to arc welding, etc. [11]. Moreover, mode conversions can occur on these extremities or these defects [12]. The radiation of the guided waves at an extremity of a plate or a tube has also been studied and angular diagrams are obtained [13,14].

Lamb waves have extensively been used in Non-Destructive Evaluation to detect defects in plates and in pipes [15,16]. Several works by a team from London Imperial College are examples of these applications [17,18]. In their studies, this team developed a software tool called DISPERSE to compute the dispersive velocity of these Lamb waves in structures [19].

All these results are used to explain the phenomena observed in the following study presented in this work.

The present study is the first step toward remote monitoring of blades on a marine current turbine, for example to detect potential defects, such as cracks or concretions. The propeller of a marine current turbine is made up of a boss with several blades. In this paper, the acoustic scattering from a blade immersed in water is studied and, in order to simplify the problem the blade is considered as a rectangular plane plate. This one is excited by an incident acoustic impulse at various incidence angles in a horizontal plane, perpendicular to the plate.

In the studied frequency domain 50–400 kHz, two types of Lamb waves can be observed when the plate is placed in vacuum: the antisymmetric Lamb wave A_0 and the symmetric Lamb wave S_0 [20]. In this paper, the theoretical propagation of the quasi-Lamb waves in an infinitely long thin plate immersed in water is studied. Particular attention is paid to the A_0 wave because of the bifurcation of its phase velocity dispersion curve in the vicinity of the speed of

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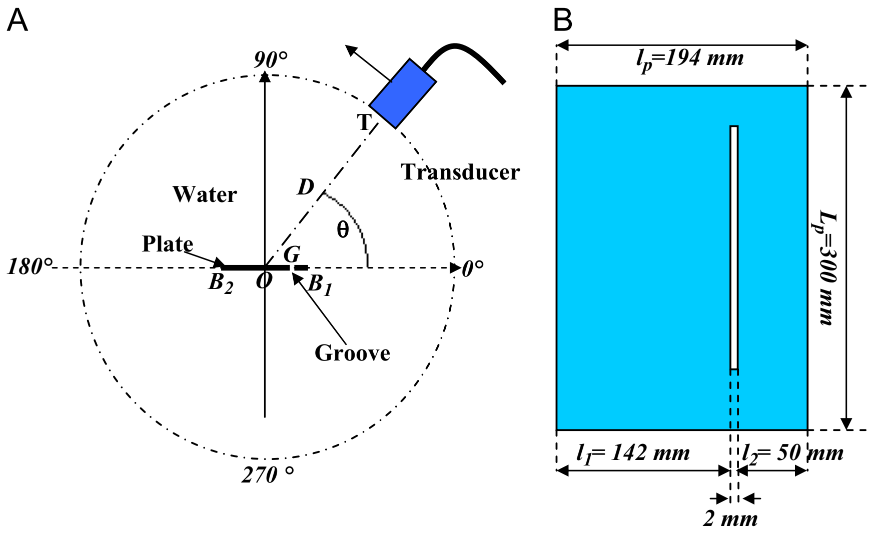

Fig. 1. (A) Experimental setup, (B) finite length plate with a groove opening out.

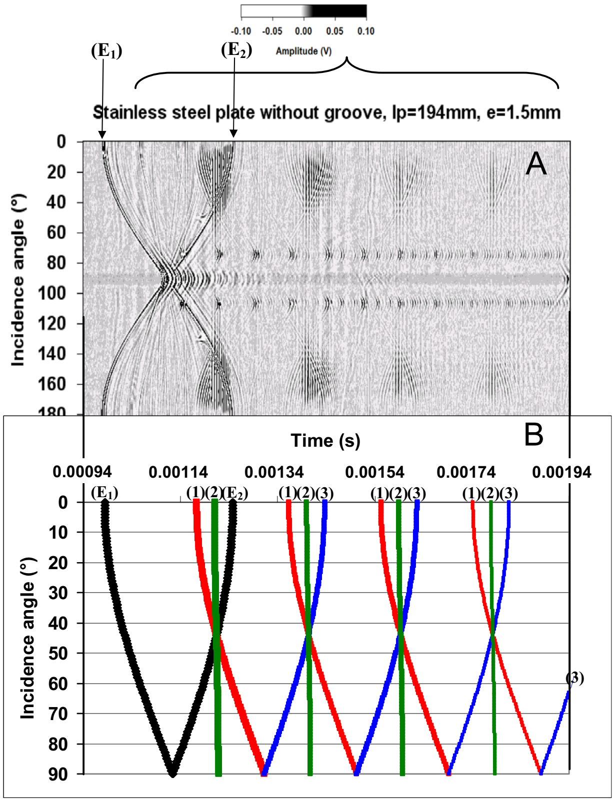

Fig. 2. (Colour online) (A) Experimental time echo trajectories in gray level obtained from stainless steel plate without groove; (B) trajectories of echoes calculated using group velocity of *A* wave. (E1) and (E2) indicate the echoes related to the edges of the plate; (1) obtained with Eq. (3), (2) obtained with Eq. (4) and (3) obtained with Eq. (5).

sound in water [21]. This phenomenon is also observed on the spherical and cylindrical shells immersed in water [22,23]. When the plate is in vacuum, the phase velocity of the A_0 wave rises from zero to the velocity of the Rayleigh wave. When the plate is in the water, the phase velocity of the A_0 wave increases with the frequency and could cross the value of the speed of sound in water, which is not possible. A repulsion phenomenon is observed in the phase-velocity dispersion curves. Two new waves replaces the A_0 wave: the *A* wave (or A_0^- wave) with a phase velocity which is always smaller than the sound speed in water and the new A_0 wave (or A_0^+ wave) with a phase velocity which is always greater than the sound speed in water [21–23].

The time signals obtained from a plate with finite dimensions allow us to explain the mechanisms of the acoustic scattering. A 2D problem is considered here, in which the guided waves set up resonances in the width of the plate due to acoustic excitation. No resonance is established in the length of the plate. The study also examines conditions for the generation of the *A* wave. Indeed, as the phase velocity of this wave is smaller than the speed of sound in water, it is not possible to generate it from the Snell–Descartes laws; however, a number of resonances are established from this wave. Therefore, in order to explain it, it is assumed that its generation takes place at the ends of the plate [11]. In the case of the S_0 wave, two modes of generation, in the plate, are experimentally observed. The phase velocity of this wave is higher than the speed of sound in water; it can therefore be generated at the critical angle defined by the Snell–Descartes Laws. This wave is also generated at the extremities of the plate or at a discontinuity such as a groove.

2. Experimental setup

The plate is vertically hung by two nylon threads in a water-filled cylindrical tank (diameter 3 m and depth 2 m). A transducer turns around the plate in a horizontal plane, perpendicular to the plate, i.e. the axis of the transducer and the vertical axis of the plate cut each other perpendicularly (Fig. 1(A)). The Olympus broadband transducer (V 3507) with a central frequency of 200 kHz is excited by an approximated Dirac impulse. The scattered time signal is composed of a series of echoes which are detected by the same transducer and, after amplification, it is digitized and visualized on a Lecroy oscilloscope. The sampling rate is 10 Msamples/s and the number of samples in a file is 10,000 for each incidence angle. This time signal is recorded on a hard disc and is processed on a Personal Computer (PC). The angular step between two measured time signals is 1° and the angular range is 0–180°. The rectangular plate used in the experiment is made of stainless steel. Its length L_p is equal to 300 mm, its width l_p is equal to 194 mm and its thickness *e* is equal to 1.5 mm. The position and the dimension of the groove opening out are indicated in Fig. 1(B). The parameter values for the stainless steel used in the computation are the velocity of the longitudinal wave $C_L = 5790$ m/s, the velocity of the shear wave $C_T = 3100$ m/s and the density $\rho_{ss} = 7900$ kg/m^3. The parameter values for water in which the plate is immersed are the sound speed $C_w = 1470$ m/s and the density $\rho_w = 1000$ kg/m^3.