The phenomenon of secondary diffraction of sound on periodically corrugated surface

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Abstract

When a sound beam is incident onto a periodically corrugated surface, diffraction of the incident sound will be generated. The major diffraction phenomenon, which can be well explained by the classical grating equation, can be easily observed and has been intensively studied. In this work, we report an observation of diffracted waves whose intensity is much weaker than the major diffraction, and who are not expected to appear in the diffraction field. This secondary diffraction can be experimentally observed in the general diffraction configuration as well as in the Bragg diffraction configuration. The analysis of the direction and frequency of the diffracted waves based on the classical grating equation suggests that this diffraction is originated from a propagating wave along the corrugated surface. Such a propagating wave is possibly the experimental evidence of the existence of surface acoustic wave on corrugated interface generated by diffraction.

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1. Introduction

The interaction of sound waves and corrugated surfaces has been intensively studied for several decades. In the past investigations a series of physical phenomena have been observed. The most readily identified phenomenon observed when a sound beam is incident onto a periodically corrugated surface is the so-called harmonic diffraction. Harmonic diffractions are the direct consequences of incident wave. They appear as high-intensity fringes in angle-
frequency domain representation of the results, and each fringe corresponds to an order (an integer number) in the classical grating equation. Another diffraction phenomenon, which is similar to harmonic diffraction, is called sub-harmonic diffraction and has been recently studied by Liu and Declercq (2014). Backward displacement of the reflected wave is also an interesting phenomenon related to the interaction of incident sound with periodic structures. It was first reported by Breazeale and Torbett (1976) and has been studied ever since by a lot of researchers such as Herbison et al. (2010).

Experimental data obtained in this study are originally in angle-time format, and then converted to angle-frequency format forming the so-called angular spectrogram as shown later in this paper. The data processing is performed using Matlab.

In this study, we report a newly observed diffraction phenomenon that has lower intensity than harmonic diffraction and whose source is obviously not the incident wave according to the classical grating equation. The experimental investigation of this unknown diffraction is based on ultrasonic polar scan technique. The angular direction and the corresponding frequency of this diffraction are analyzed in the efforts to find its source and diffraction mechanism.

2. Experiment

The experimental investigation is performed on a periodically corrugated brass block which a periodically corrugated area on one of its side. The corrugations have a period of 178 μm and height of 25 μm; and the corrugated area is 26 mm long and 25 mm wide. Compared with the dimensions of the sound beams used in this study, this area is large enough to eliminate the effect caused by the side/boundary reflections.

The experiments are performed in water and the immersion transducers chosen for the current investigation are two sets of single element transducers: ‘Valpey Fisher’ transducers of 10 MHz and ‘NDT Systems’ transducers 20 MHz. Both sets of transducers have relatively broad frequency coverage about their respective center frequency, and this feature facilitates the need of examining the phenomenon investigated in this work over a large frequency range.

Two experimental configurations, i.e. Bragg diffraction and general diffraction, are applied in this work. In the so-called Bragg diffraction configuration, one transducer is used and only the back scattered diffraction waves are captured for analysis. The scan is performed over an angular range of 140º from -70º to 70º about the surface normal (0º) of the scanned surface. In the general diffraction configuration, two transducers, i.e. an emitter and a receiver, are used; and the diffraction field of the sound incident at a specific angle is captured for analysis. In this work, the incident angle is 0º and the polar scan is performed over 12º to 95º.

![Fig. 1. Experimental configurations of polar scan for diffraction field: (a) Bragg diffraction; (b) general diffraction.](image)

Experimental data obtained in this study are originally in angle-time format, and then converted to angle-frequency format forming the so-called angular spectrogram as shown later in this paper. The data processing is performed using Matlab.
3. Results and discussions

3.1. Bragg diffraction

The angular spectrogram obtained in Bragg diffraction configuration is shown in Fig. 2. As seen in Fig. 2(a) there appear three types of diffraction phenomena: harmonic diffraction, sub-harmonic diffraction and unknown diffraction. The angle-frequency fringes of harmonic diffraction are clear and symmetric. These fringes can be perfectly explained by the classical grating equation for Bragg diffraction as developed by Liu et al. (2012):

\[ \theta_{Bragg} = \arcsin\left(\frac{mv}{2\Lambda f}\right) \]  

where \( \theta_{Bragg} \) is Bragg angle as shown in Fig. 1(a), \( v \) the sound velocity in water, \( \Lambda \) the periodicity of corrugations, \( f \) frequency and \( m \) the order of diffraction which can be 0, ±1, ±2, ±3, ±4, and ±5, respectively. In between the harmonic diffractions are a series low-intensity fringes with similar shape to harmonic diffractions and they are called sub-harmonic diffractions. Besides harmonic and sub-harmonic diffractions, there are four symmetric diffraction fringes going across the above diffraction fringes whose source remains unknown up to date.

![Angular spectrogram obtained in Bragg diffraction configuration](image)

Fig. 2. Angular spectrogram obtained in Bragg diffraction configuration: (a) experimental result; (b) experimental result with predicted angle-frequency fringes (dotted lines) originating from propagating surface waves by the classical grating equation.

In order to find the source of the observed unknown diffraction, the authors first assume that the classical grating equation is still valid, and then obtain the angle-frequency values of these fringes and fit them back to the general form of the classical grating:

\[ \sin \theta_m + \sin \theta_{inc} = \frac{mv}{\Lambda f} \]  

After trying different possible orders, it shows that these four unknown fringes can be explained if we assume that their source waves are incident along the surface, i.e. incident angle of ±90°. We plot the diffractions of -1 and -3 order for -90° incidence and +1 and +3 order for 90° incidence in the experimental angular spectrogram as shown in Fig. 2(b). It can be readily observed that these four fringes perfect match the unknown diffractions. Based on this observation it is reasonable to believe that a type of surface acoustic wave is generated on the corrugated surface and
that it travels along the surface in both directions. The propagating surface waves are diffracted by surface corrugation, that is, secondary diffractions are generated and lead to the appearance of the unknown diffractions.

3.2. General diffraction

In order to check if the diffraction discussed above is a unique phenomenon for Bragg diffraction, the experiment is also carried out in the general diffraction configuration and the resulting angular spectrogram is shown in Fig. 3. Similar to Fig. 2 three types of diffractions, i.e. harmonic diffraction, sub-harmonic diffraction and unknown diffraction fringes can be observed. The same data processing procedure is repeated on the unknown diffraction observed in Fig. 3 (a), and the diffraction fringe of -1 order for -90° incidence is found to be perfectly matching with the unknown diffraction. Therefore, we can safely say that surface acoustic wave of some kind is also generated in the general diffraction configuration.

![Image of angular spectrogram obtained in general diffraction configuration]

4. Conclusions

This work reports a secondary diffraction phenomenon experimentally observed in both Bragg diffraction and general diffraction configurations. In the search of the physical source of this unknown diffraction, the data analysis based on the classical grating equation suggests that it originates from propagating wave on the corrugated surface, which is probably generated by the coupling of incident wave with the surface corrugation.

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References


