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Kiran Kumar Amireddy, Krishnan Balasubramaniam and Prabhu Rajagopal

Deep Sub-wavelength Ultrasonic Imaging

Kiran Kumar Amireddy*, Krishnan Balasubramaniam, Prabhu Rajagopal

Centre for Nondestructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai 600036,Tamil Nadu, India

*amireddykiran@gmail.com

Abstract: There is much interest in improving the resolution of ultrasonic inspection, which suffers from large wavelengths typically in the range of millimeters, due to low value of speed of sound in solid media. The authors are interested in achieving this through holey structured metamaterial lenses, and have recently demonstrated an experimental subwavelength resolution of λ/25. However the previous work was in through-transmission mode with reception using Laser Doppler Vibrometer (LDV), which may not be suitable for practical applications. This paper discusses the use of optimized holey structured metalens to achieve a deep sub-wavelength imaging up to λ/18 in through-transmission mode, but using commercially available piezoelectric ultrasonic transducers for both generation and reception of ultrasound.

Keywords: Ultrasonic imaging, metamaterials, super resolution, sub-wavelength imaging.

INTRODUCTION

In recent years, extraordinary optical transmission through media with subwavelength hole arrays has drawn much research attention [1-4]. Recently, such concepts have also been extended for acoustics [5-9]. It has widely accepted that Fabry-Perot resonances are mainly responsible for extraordinary acoustic transmission [10, 11].

More recently our group reported the application of holey structured metamaterials to achieve extraordinary transmission and subwavelength resolution in the ultrasonic regime [12,13]. We also demonstrated that extraordinary transmission properties can be tuned and improved by changing the size, length and period of the holes in the metamaterial lens [14].

In such previous work, and the reception was performed using a Laser Doppler Vibrometer (LDV). However, the use of lasers for reception may not be suitable in practical industrial settings.

The aim of this paper is to experimentally demonstrate the feasibility of subwavelength imaging (λ/18) of defects in metallic materials using holey-structured metamaterial with conventional (PZT) transducers for both the generation and reception of ultrasound.

BACKGROUND

Holey structured metamaterials work on the principle of Fabry-Perot resonances inside extended cavities or holes. When scattered waves from an artifact of interest propagate through the holes, Fabry-Perot resonances take place, enhancing higher frequency and evanescent wave components. Thus the meta-lens transfers both propagating and evanescent wave components from input to output surface. Thus subwavelength information carried by the evanescent waves helps to create the image with high resolution [8, 10].

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Problem Studied

We consider an aluminium sample having a subwavelength side drilled through-notch of length 1.5 mm as shown in Figure 1. The length of the notch (1.5 mm) is about λ/18 at the central frequency of 244 kHz. This sample is imaged by ultrasonic immersion in through-transmission mode to resolve the subwavelength notch dimensions with the help of an optimized periodic holey-structured metamaterial lens.

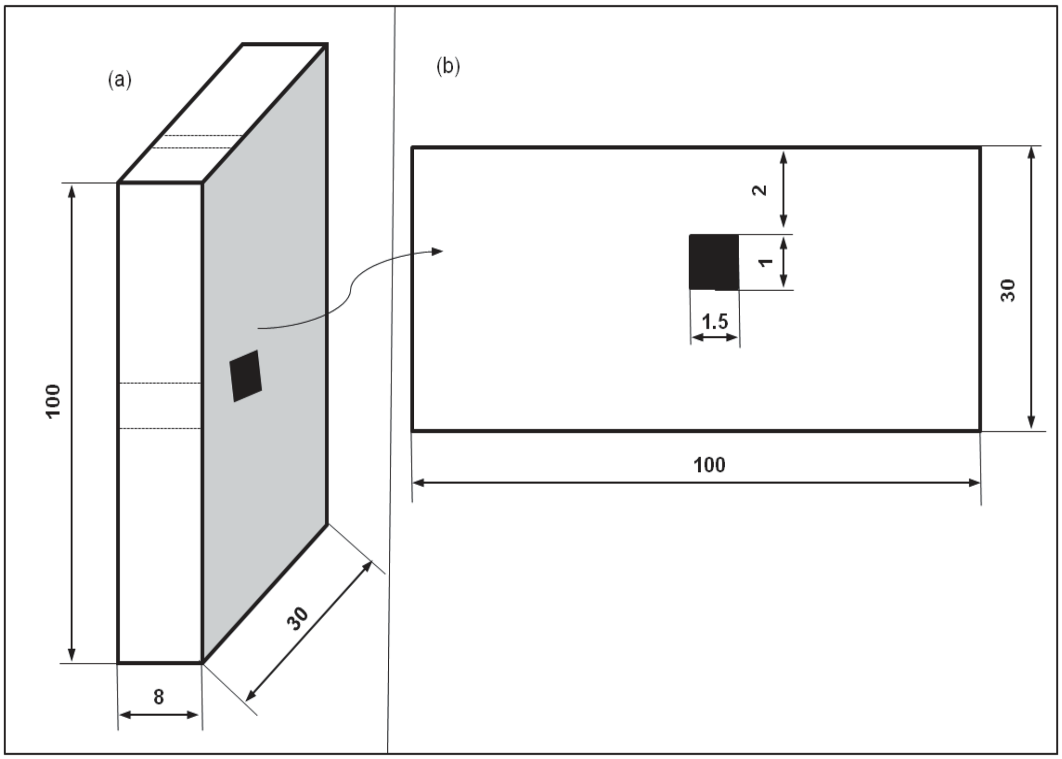

FIGURE 1. Schematic diagram of aluminium sample with details of subwavelength side drilled through notch presented in it (dimensions are in mm). (a). Front view and (b). Cut section view.

EXPERIMENTAL PROCEDURE

The experimental setup is based on the ultrasonic immersion C-scan imaging technique [15] using through-transmission mode as illustrated in Fig. 2(a). In immersion ultrasonic transducer (Panamatrics V318, GE measurement & Control) was used to provide excitation at 244 kHz. The excitation controlled of a 3 cycle Hanning windowed tone burst as provided by a RITEC RPR4000 Pulser-Receiver (Ritec Inc., USA). The aluminium sample with a subwavelength notch is placed in front of the transducer in the immersion tank.

A holey structured metamaterial with optimal dimensions for 244 kHz (see [14] for details) as shown in Fig. 2(b) is then placed in front of the sample so that the scattered waves from the notch are propagated through it. The scattered wave fields are detected using another immersion ultrasonic probe (Panametrics-NDT, V303, USA) of central frequency 1 MHz. The output from the receiver is fed to a computer for storage. The whole set up (transducers, aluminium sample and metamaterial) is immersed in the water for immersion scan. The receiver was attached to a 3-D scanner consisting of a National Instruments PCI 7330 (NI Inc., USA) motion controller to record the signals at regular intervals of 0.01 mm with the index of 0.1 mm to complete a C-scan.

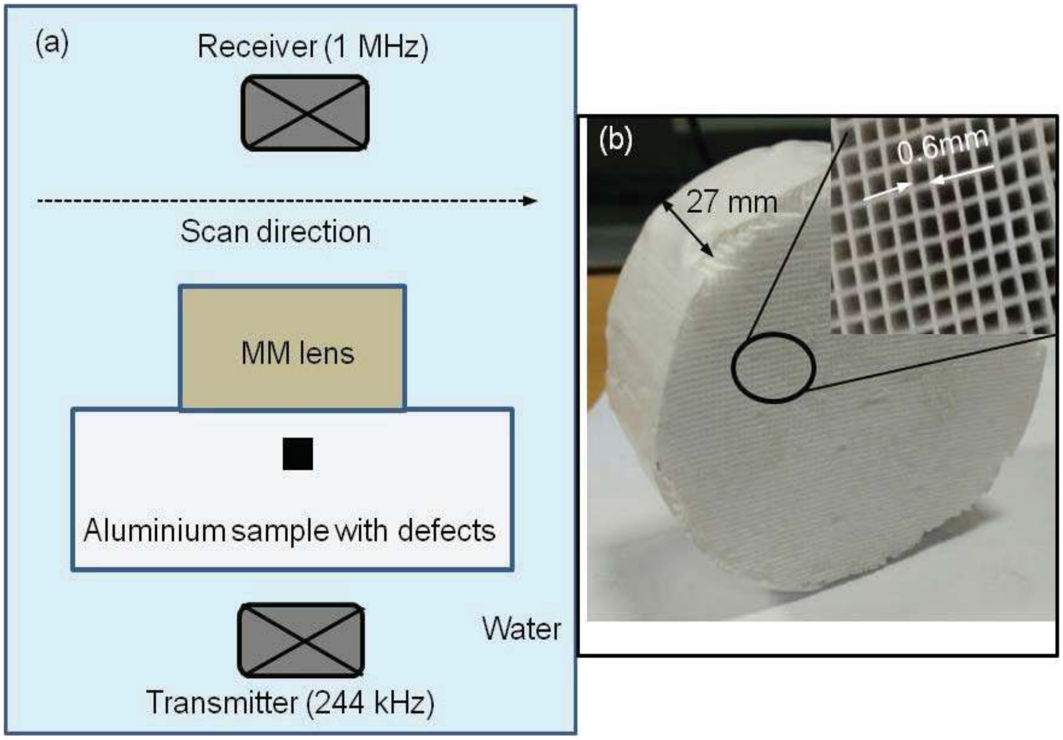

FIGURE 2. (a) Illustration of the experimental setup
(b) Photograph of the optimized holey structured metamaterial.

RESULTS AND DISCUSSION

After completion of the scan the maximum amplitude variation across the measurement positions is represented with a color scale (image) also known as C-scan image [15]. The experiment was performed without and with the metamaterial lens between the test sample and the receiver. The corresponding C-scan image was created without and with metamaterial lens and the comparison is shown in Fig. 3. We can identify the subwavelength notch present in the aluminium sample in the image obtained with the optimized holey structured metamaterial lens. In the image obtained without the metamaterial the subwavelength notch is not identifiable.

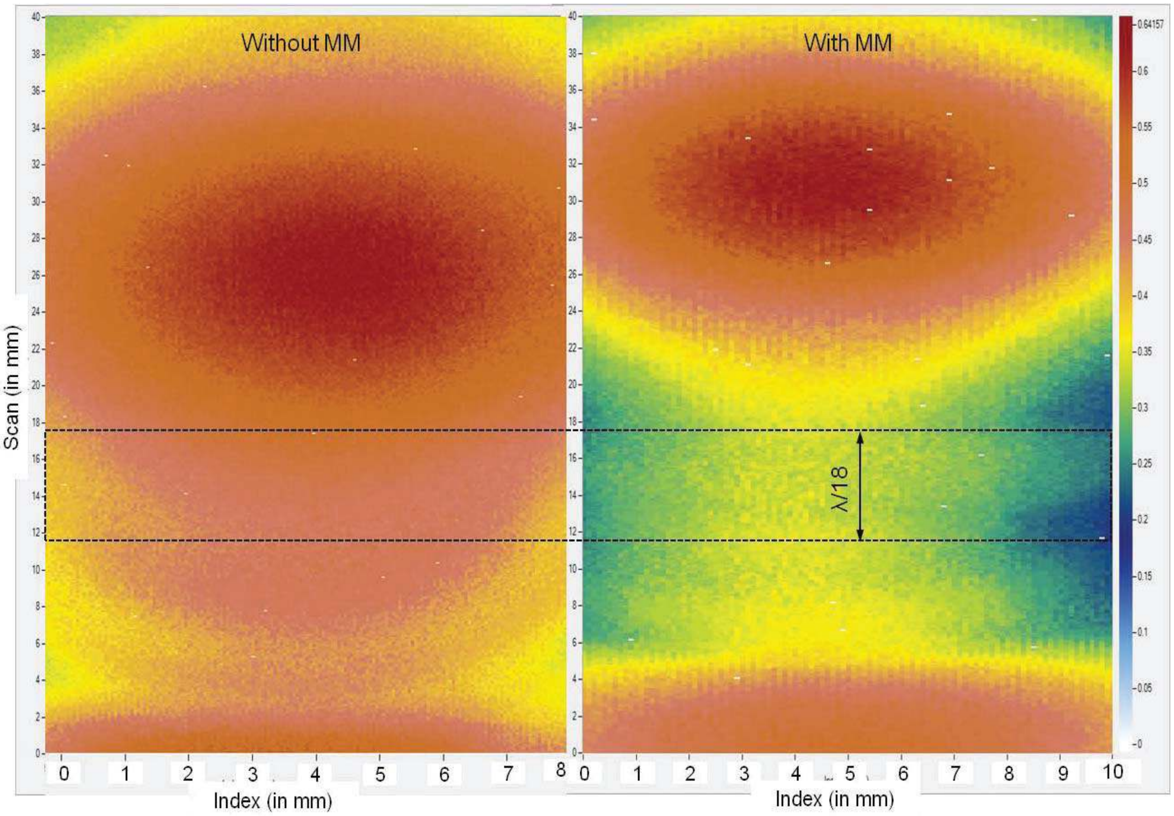

FIGURE 3. Experimental results showing the ultrasonic C-scan image (a) without metamaterial and (b) with metamaterial lens. The dashed box indicates the subwavelength crack in the aluminium sample, which is clearly resolved with metamaterial lens.

CONCLUSION

This paper demonstrated holey-structured metamaterial lens for resolving a subwavelength (λ/18) sized notch in an aluminium sample in the through-transmission mode, using commercially available piezoelectric transducers. The proposed technique can be useful to detect and characterize subwavelength sized defects in industrial components.

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