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CHANNEL STRUCTURED METAMATERIALS FOR SUPER RESOLUTION IMAGING

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ABSTRACT

When inspection is required to be conducted from a remote distance, due for example to safety concerns, guided ultrasonic wave testing technique is the preferred choice. Guided waves are usually low frequency hence are not subjected to much attenuation relative to the bulk waves. As a result, guided waves can travel a longer distance. One of the limitations of guided waves however, is that the low frequency (longer wavelength) used lead to lower resolution capabilities due to the inherent diffraction limits of λ/2 (where λ is wavelength). Guided waves are therefore generally used as screening tools to locate areas of interest. A higher resolution technique is then employed to further investigate and characterize the features of defects in the identified areas.

To overcome this challenge of resolution, a technique is proposed that increases the resolution capability of guided waves beyond the diffraction limit. Simulation using commercial finite element software is used to optimize variables involved in the proposed method. The simulation is then validated with experiments. In the present work a resolution of λ/72 is demonstrated experimentally.

Keywords: guided waves, super resolution, metamaterials

NOMENCLATURE

λ	wavelength

1. INTRODUCTION

Long range ultrasonic testing (also known as guided wave testing) is an important non destructive technique of much interest to asset integrity management. This is particularly relevant where close contact with a target structure of interest is impossible, risky or involves expensive procedures [1-4]. All wave modalities are limited in defect resolution to half the operating wavelength [5]. However, the diffraction limit poses further challenges to guided waves where the λ is several centimeters. The implication of this is that defects close to design features such as welds can easily go undetected.

This challenge is not unique to mechanical waves only. Studies done in other fields have demonstrated the possibility of overcoming diffraction limits [6-9]. In optics for instance, resolution of hundredths of wavelength have been reported in literature. Similarly, in acoustics, resolution at the subwavelength level has been achieved. Recently, our CNDE research group at IIT Madras has demonstrated successes in subwavelength imaging for bulk ultrasonic waves [5,

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10, 11]. In this work, the objective was to develop a technique that enable resolution at the subwavelength regime for guided ultrasonic waves.

2. MATERIALS AND METHODS

The work reported here was obtained through finite element simulation software and validated by experiments. For the experimental procedure, a flat bar test sample measuring 10mm thickness by 50mm width by 1000mm length was fabricated. Two side drilled holes were fabricated onto the side of the bar separated by 1mm. The bar was excited with S0 mode guided ultrasonic waves from one end. A piezoelectric transducer was used for the excitation while the sample was immersed in water. At the location of the side drilled holes, the developed channel structure was positioned accordingly. A laser vibrometer was used to detect the displacements of the bar perpendicular to its axis. All the experiment parameters and set up above was arrived at based on optimized finite element simulations.

3. RESULTS AND DISCUSSION

Results from simulation agrees well with experiments. The aim of the study was to develop a technique that enable imaging at subwavelength level. This was done using specially designed materials. These materials obtain their special properties by virtue of shape and pattern. The pattern consists of a series of empty space and solid parts. By properly designing the dimensions of these materials, the Fabry-Perot resonance is achieved with transmission coefficient greater than one being possible. Through simulations, these parameters (namely hole size, solid part size, repeating pattern, and length) were optimized. Experiments were then conducted to validate these results. It was determined that these parameters are effective based on a specific set of relations with wavelength used. Using the specially designed materials incorporated in the guided wave inspection system, a resolution of $\lambda/72$ was achieved as indicated in FIGURE 1 for the sample discussed in methodology. The rectangular boxes in the figure indicates the positions of defects.

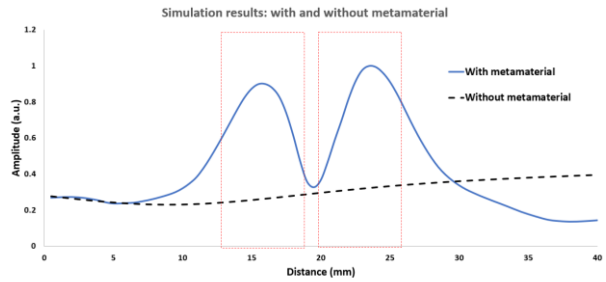

FIGURE 1: SIMULATION RESULTS FOR DEFECT RESOLUTION FOR CASE WHERE METAMATERIAL IS USED AND WHEN THERE IS NO METAMATERIAL

4. CONCLUSION

The objective of this work was to improve resolution of defects beyond the diffraction limit for guided wave inspection of flat bars. This was achieved by simulations and validated through experiments. Channel structured metamaterials were optimized through simulations. The structure was then designed and developed. By coupling the developed metamaterial to existing guided wave inspection system it was possible to distinctly image two defects separated by $\lambda/72$. Without the incorporation of the structure to inspection system, the defects were not detectable. This is the first time such resolution has been achieved in guided wave inspection systems. This has much potential for remote inspections whereby now it is possible to detect defects located close to design features such as welds and supports using the long-range guided waves. This will lead to improved safety of critical assets such as nuclear power plants. Further work is ongoing to improve resolution further for the given defect geometry and to achieve sub-wavelength resolution for other defect types.

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