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HIGHER HARMONICS SUPPRESSION USING NONLINEAR WAVEGUIDE METAMATERIAL ROD

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ABSTRACT

Guided Ultrasonic Waves (GUW) inspection is an important method of Non-Destructive Evaluation (NDE) used for the inspection of pipelines, storage tanks and pavements owing to their sensitivity and long range propagation. Nonlinear Ultrasonics (NLU) are used for the enhanced inspection of structures by increasing the sensitivity of measurements to detect micro cracks and defects. However, there could be a lot of false positives because apart from material based nonlinearity or micro-crack based nonlinearity, it could also arise from equipment electronics, nonlinearity due to transducer and couplant etc. To reduce the false positives and improve the detection of ultrasonic guided wave signals, here we propose a new technique of using a waveguide metamaterial rod by creating bandgap wherein wave propagation of higher harmonics is hindered. The proposed metamaterial waveguide demonstrates its capability of suppressing all higher harmonics experimentally. This will help to improve in the ultrasonic guided wave measurements more accurately as they are free of nonlinearities. The proposed waveguide metamaterial made of Aluminium consists of an array of baffles which are arranged periodically along the surface of the rod. This could help in improved ultrasonic measurements using waveguide sensors which find important application for like fluid rheological properties, flow and temperature.

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Keywords: Metamaterials, Waveguide, Cylindrical rods, Nonlinear Ultrasonics, Higher Harmonic Suppression

NOMENCLATURE

GUW	Guided Ultrasonic Waves
NDE	Non-Destructive Evaluation
NLU	Nonlinear Ultrasonics

1. INTRODUCTION

Ultrasonic guided waves are elastic waves confined to extended structures such as plates, pipes and rods. Guided waves are attractive for rapid inspection of infrastructural assets such as pipelines, pavements and storage tanks, is primarily because fundamental modes can propagate long distances from a single location and also have a through-thickness signature. Nonlinear ultrasonic guided waves have the advantages of long range inspection as well as the ability to inspect micro and fatigue cracks. However accurate measurement is hampered by the fact that higher harmonics due to material and equipment (cables, couplant etc) are difficult to separate from the main signals. Such higher harmonics would lead to false positives, and it is of much interest to suppress them. One of the possible ways to address this problem is by using metamaterials.

Metamaterials are artificially engineered materials that exhibit unique properties that are not typically found in nature. Ever since the demonstration by Pendry(Pendry 2000) in 2000's, various metamaterial concepts were introduced for applications including bandpass filters. cloaking devices, wave absorbers, and seismic protection(Miniaci et al. 2017)[3][4](Tian and Yu 2017). Recently, the author's group experimentally demonstrated deep subwavelength ultrasonic imaging using holey-structured metamaterial lens, and wavefront control using phononic crystal.

This article discusses the use of a novel ridged rod (see FIGURE 1) as a waveguide metamaterial to achieve the goal of suppressing NLU higher harmonics. Experimental studies on an Aluminium rod with and without baffles are conducted. Signals were measured in pitch-catch configuration. Frequency domain signals are shown for both cases and the phenomenon of suppression of higher harmonics in Aluminium rods by the introduction of baffles is demonstrated.

2. Experimental Study

Guided Ultrasonic Waves experiments with the circular rod mode L(0,2) were conducted on a sample with the proposed waveguide concept with a goal of suppressing higher harmonics. The ridged waveguide metamaterial is made of Aluminium which consists of baffles along the surface introduced by turning

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operation using Computer Numerical Control (CNC) machining. The experimental set-up consists of two contact transducers (V101-0.5MHz Panametrics Inc., Waltham, MA, USA), one at the excitation end and the other at the receiving end of the rod. Ultrasonic guided waves of the longitudinal family are generated using a commercially available transducer of central frequency of 500 kHz. A 10 cycle toneburst Hanning windowed pulse generated by the RITEC advanced measurement system RAM-5000 SNAP (RITEC, Warwick, USA) in pitch-catch configuration. The signals obtained from the transducer connected at the receiving end are displayed and recorded using a digital storage oscilloscope (DSO-X-4104A, Keysight Technologies, USA). The same experiments were also repeated on an Aluminium rod without baffles for comparison.

FIGURE 1: Photograph of Waveguide metamaterial sample with and without baffles.

3. RESULTS AND DISCUSSION

The frequency spectrum was extracted from the time domain results recorded in the experiments, and results obtained for cases without and with baffles are shown in Figure 2(a) and (b) respectively. It is observed that higher harmonics which were present at frequencies 1MHz, 1.5MHz, 2MHz etc. in plane rod without metamaterial (MM) are seen in FIGURE 2(a) are absent in the rod with ridges see FIGURE 2(b).

The suppression of higher harmonics is due to the Bragg scattering phenomenon occurring in the waveguide metamaterial rod. The baffles placed on the surface of the rod are strongly reflecting back the higher harmonics. The Bragg scattering occurs around the frequencies governed by the Bragg condition

$$L = n\,(\lambda/2) \quad (n=1,2,3\ldots\ldots) \qquad (1)$$

Where, L is the lattice constant of the periodic system, λ is the wavelength of the wave in the material.

4. CONCLUSION

This paper proposes a new concept of suppressing higher harmonics using a cylindrical ridged waveguide metamaterial. The proposed concept is verified by conducting ultrasonic experiments for generating longitudinal wave modes. Frequency domain signals are shown for with and without a baffle type metamaterial on a specimen Aluminium sample. The phenomenon of suppression of higher harmonics in Aluminium rods was demonstrated. Further, by adjusting the parameters of the baffles such as height, pitch and thickness, the range of the bandgap formed can be altered and also it can be used for suppressing certain specific harmonics. This work of selective harmonic suppression is currently being further investigated and will be reported in the near future.

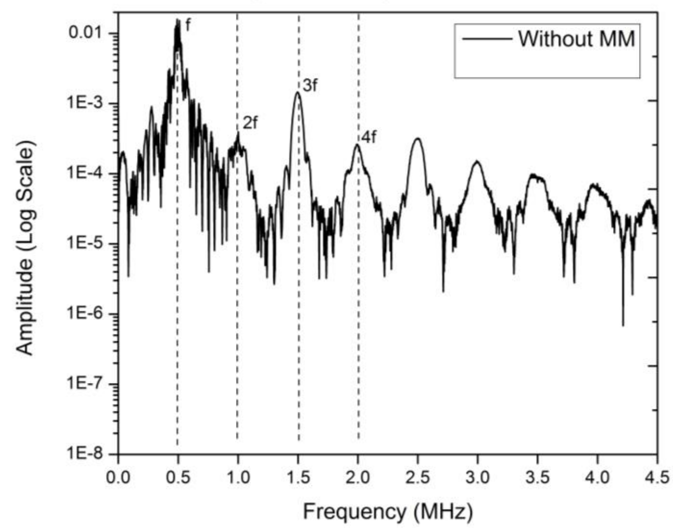

FIGURE 2(a): Frequency spectrum of the transmitted wave obtained from experiments for without Metamaterial.

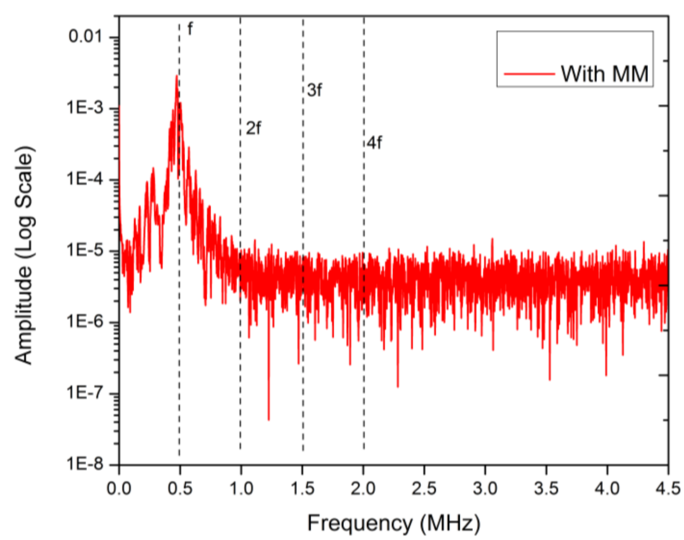

FIGURE 2(b): Frequency spectrum of the transmitted wave obtained from experiments for with Metamaterial.

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