46th Annual Review of Progress
in Quantitative Nondestructive Evaluation
QNDE2019
July 14-19, 2019, Portland, OR, USA

QNDE2019-6721

PROGRESS ON THE DEVELOPMENT OF MAGNETOSTRICTIVE PATCH TRANSDUCERS FOR ULTRASONIC GUIDED WAVES INSPECTION

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ABSTRACT

Ultrasonic guided waves method has some advantages including long-range inspection ability and high sensitivity to multiple types of defects in structures. Electromagnetic acoustic transducer is an attractive choice to achieve the excitation and reception of ultrasonic guided waves. This type of transducer can be easily designed and well control the purity of targeted ultrasonic guided waves modes. In common, traditional EMAT only consists of magnet and coil. In ferromagnetic material, the energy conversion efficiency of EMAT based on magnetostriction is higher than that of EMAT based on Lorentz force. For improving the energy conversion efficiency and adaptability of EMAT, a thin ferromagnetic patch (such as nickel and iron-cobalt alloy) is introduced and therefore magnetostrictive patch transducer (MPT) based on magnetostriction is developed regardless of the material properties of tested structures. In this paper, two types of MPTs for pipe inspection are introduced. These two MPTs can achieve the excitation and reception of longitudinal and torsional modes, respectively. Furthermore, a direction-tunable shear horizontal mode MPT is introduced and its characteristics are evaluated. Finally, the application potentials of MPTs in nondestructive testing and structural health monitoring are discussed.

Keywords: ultrasonic guided waves, EMAT, magnetostrictive patch transducer, defect, magnetostriction effect

1. INTRODUCTION

Ultrasonic guided waves method has some advantages including long-range inspection ability and high sensitivity to multiple types of defects in pipes and plates structures.

There are three ultrasonic guided wave modes in cylindrical waveguides: longitudinal, torsional, and flexural modes. The axisymmetric torsional and longitudinal guided wave modes are the most widely used for pipe inspection [1, 2]. The torsional mode is preferred in the nondestructive testing of pipelines because the fundamental torsional mode, T(0,1), is totally non-dispersive and hence travels a long distance without any signal distortion. Furthermore, this T(0,1) mode shows great potential and advantages in pipe inspection [3-5]. The longitudinal guided wave mode L(0,2) is practically non-dispersive over typical frequency ranges and its particle motion is roughly uniform throughout the pipe wall. The axial displacement of L(0,2) mode within a certain frequency range is larger compared to its radial displacement, therefore L(0,2) mode shows the good attenuation performance [6]. L(0,2) mode generated by magnetostrictive transducer is an effective choice for the long-range pipe inspection. Kwun et al. [7, 8] proposed a longitudinal guided wave EMAT based on the magnetostriction mechanism.

The shear horizontal (SH) waves are one of type of ultrasonic guided waves and their vibration direction is parallel to the plane and perpendicular to the propagation direction. Since the SH waves have a characteristic that the oblique incident on a free plane does not produce mode conversion [9], its application in the field of ultrasonic nondestructive testing has become more and more extensive.

Electromagnetic acoustic transducers (EMAT) is an attractive choice to achieve the excitation and reception of ultrasonic guided waves in metal plates and pipes [10, 11]. This type of transducer can be easily designed and well control the purity of targeted ultrasonic guided waves modes. In common, traditional EMAT only consists of magnet and coil. In ferromagnetic material, the energy conversion efficiency of EMAT based on magnetostriction is higher than that of EMAT based on Lorentz force. For improving the energy conversion efficiency and adaptability of EMAT, a thin ferromagnetic patch (such as nickel and iron-cobalt alloy) is introduced and therefore magnetostrictive patch transducer (MPT) based on magnetostriction is developed regardless of the material properties of tested structures.

In this paper, two types of MPTs for pipe inspection proposed by us are introduced. These two MPTs can achieve the excitation and reception of torsional and longitudinal modes, respectively. Furthermore, a direction-tunable shear horizontal mode MPT is introduced and its characteristics are evaluated. Finally, the application potentials of MPTs in nondestructive

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testing and structural health monitoring are discussed.

2. CONFIGURATION AND WORKING PRINCIPLE OF THREE PROPOSED MPTS

2.1 Modified planar solenoid array coil MPT (MPSA coil-MPT)

Fig. 1(a) and (b) respectively show the configuration and working principle of the proposed torsional mode MPSA coil MPTs array in the three-dimensional and cross-sectional views [5]. It consists of MPSA coil with special winding strategy, a magnetostrictive patch tightly bounded around a pipe surface, and permanent magnets with a sector cross-section. The permanent magnets are uniformly placed on the patch around the pipe to supply the circumferential static magnetic field to the patch. When the suggested MPSA coil modified from the mentioned PSA coil carries an alternating current, the dynamic magnetic field can be generated, as illustrated in Fig. 1. Because the static and dynamic magnetic fields are perpendicularly applied onto the patch, the shear deformation of patch tightly boned around the pipe will be caused by magnetostriction. Meanwhile, the pipe will experience the same deformation as the patch because of the mechanical coupling. Then, the torsional mode T(0,1) is successfully generated in the pipe and propagates along the pipe wall in the axial direction.

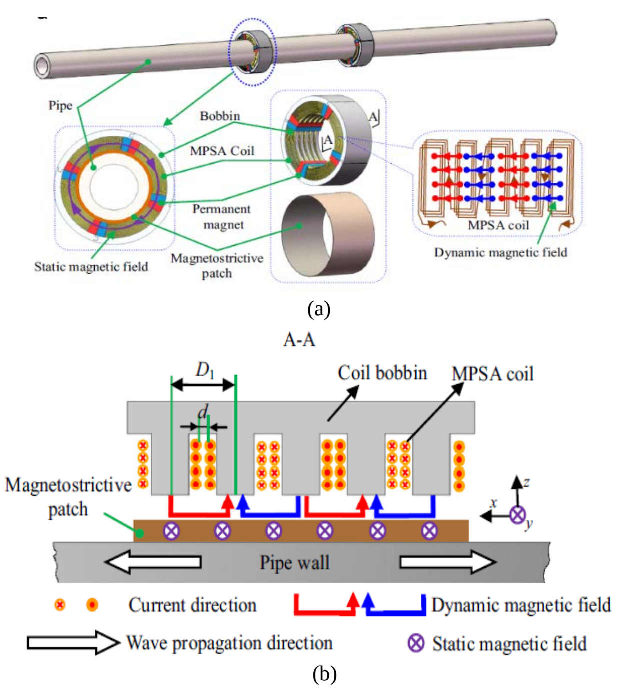

Fig. 1. Configuration and working principle of proposed torsional mode MPSA coil-MPTs array (a) three-dimensional view and (b) cross-sectional view.

2.2 Multi-splitting meander coil MPT (MSMC–MPT)

Fig. 2 shows the proposed longitudinal modes magnetostrictive patch transducers array employing MSMC (MSMC-MPTs array), respectively [11]. It consists of three components: a 0.10-mm thick nickel patch, which is a magnetostrictive material and tightly bound around a pipe surface, a two layer multi-splitting meander coil (MSMC), and permanent magnets with a sector cross-section. The principle that an EMAT generates longitudinal guided wave mode in a pipe is shown in Fig. 2(b). The permanent magnet and the MSMC will respectively induce the static bias magnetic field and dynamic magnetic field along the pipe axis. Under the action of the static bias magnetic field and dynamic magnetic field, the magnetostrictive force is generated to cause the time variant mechanical deformation of the patch. Then, the patch deformation generates longitudinal guided wave mode L(0,2) in the pipe because the patch is tightly bonded on it.

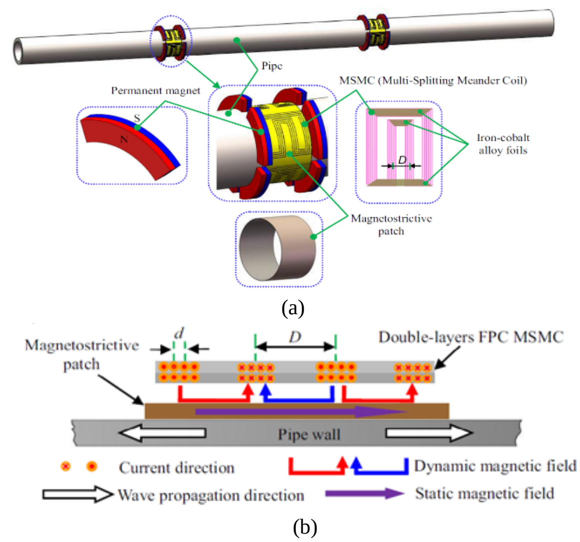

Fig. 2. Configuration and working principle of the proposed longitudinal modes magnetostrictive patch transducers array employing MSMC (a) three-dimensional view and (b) cross-sectional view.

2.3 Direction-tunable shear-horizontal mode array MPT (DT-SHMA-MPT)

In order to excite and receive SH_0 mode in non-ferromagnetic or weakly ferromagnetic plates based on the magnetostrictive effect, the DT-SHMA-MPT is proposed and illustrated in Fig. 3 [9]. The transducer consists of a group of fan-shaped permanent magnet, a coil array, a piece of circular nickel patch, and a support sleeve. The circular nickel patch is glued onto the surface of the aluminum plate with a commercial epoxy resin adhesive. The support sleeve with permanent magnets is placed on the circular nickel patch and a circumferential static magnetic field can be formed. The coil array consists of four identical centrally symmetric planar fan-shaped meander coils. When an AC current is connected to the coil array, i.e., four planar fan-shaped meander coils, the opposite dynamic magnetic fields are generated in the two adjacent wires in the radial direction of the coil array and the generated magnetic fields are parallel to the radial direction of nickel patch. Under the interaction between the radial dynamic magnetic field along the radial direction and the bias static magnetic field along the circumferential direction of the nickel patch, the shear deformation of the nickel patch will be generated due to the magnetostrictive effect. This shear deformation is transferred to non-ferromagnetic or weakly ferromagnetic plate such as aluminum plates, implying that shear horizontal waves are finally excited.

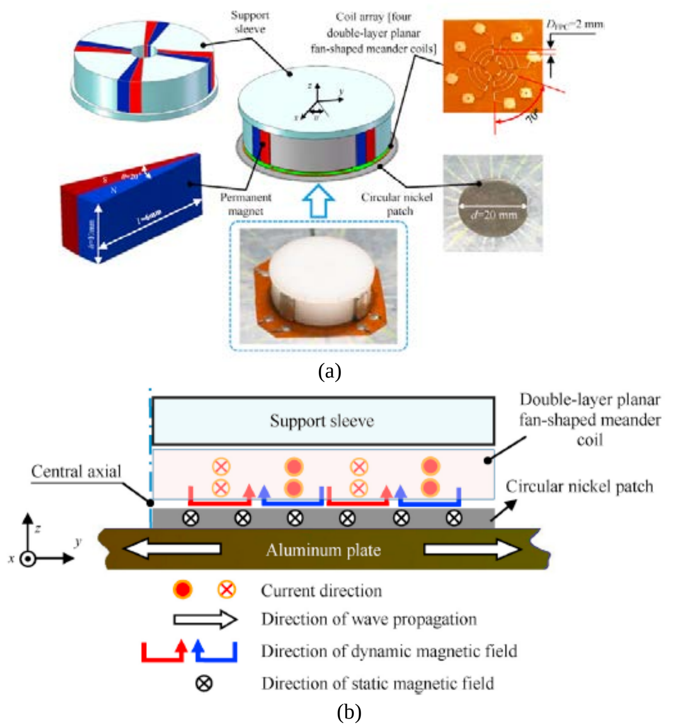

Fig. 3. Configuration and working principle of the proposed DT-SHMA-MPT (a) Schematic diagram of the proposed DT-SHMA-MPT (b) working principle

3. MPTS FOR NDT APPLICATIONS IN PIPES AND PLATES

Traditional EMAT only consists of magnet and coil. In ferromagnetic material, the energy conversion efficiency of EMAT based on magnetostriction is higher than that of EMAT based on Lorentz force. For improving the energy conversion efficiency and adaptability of EMAT, a thin ferromagnetic patch (such as nickel and iron-cobalt alloy) is introduced and therefore MPT based on magnetostriction is developed regardless of the material properties of tested structures.

The magnetostrictive patch is one of the most important components in the developed MPSA coil-MPTs array [5] (illustrated in Fig. 1), the material with the low eddy current loss and large magnetostriction can greatly improve the performance of the MPTs array. The magnetostrictive patch used is the 0.10-mm thick nickel patch due to the rather high magnetostriction and the low price. In order to avoid sudden discontinuities between the bare and patch-bonded parts of the pipe, reduce the internal reflection, and alleviate the waveform distortion problem, the 2-mm wide regions in the edges of the nickel patch are machined so as to guarantee the gradual thickness variation.

The magnetostrictive patch transducer [11] (illustrated in Fig. 2) is a good choice of generating and receiving longitudinal guided waves for pipe axial inspection. Several customized permanent magnets were adopted to supply an axial static magnetic field for the nickel strip installed on the pipe surface. Meanwhile, the proposed MSMC carrying an alternating current also provides a dynamic magnetic field along the axis in the nickel strip. The mechanical deformation of nickel strip is formed and then transferred to the pipe, thus contributing to the generation of the longitudinal modes in the pipe.

In order to excite and receive SH_0 mode in non-ferromagnetic or weakly ferromagnetic plates based on the magnetostrictive effect, the MPT shown in Fig. 3 can be used [9]. The bias static magnetic field along the circumferential direction of the nickel patch. The opposite dynamic magnetic fields are generated in the two adjacent wires in the radial direction of the coil array and the generated magnetic fields are parallel to the radial direction of nickel patch. The ultrasonic guided waves are generated due to the interaction between the static and dynamic magnetic fields. The shear deformation of the nickel patch will be generated due to the magnetostrictive effect. This shear deformation is transferred to non-ferromagnetic or weakly ferromagnetic plate such as aluminum plates, implying that shear horizontal waves are finally excited.

4. CONCLUSIONS

Through a review of various magnetostrictive patch transducers, this paper argued that the energy conversion efficiency and adaptability of EMAT can be improved by using magnetostrictive patch. An understanding of the operational magnetostrictive phenomena is important for the design of MPTs. Ultrasonic guided waves can be excited and received by using MPTs to achieve non-destructive testing and structural health monitoring of pipes and plates structures.

ACKNOWLEDGEMENTS

The study was supported byNational Key R&D Program of China (No. 2018YFC0809003), and the National Natural Science Foundation of China (Grant Nos. 11772014, 51475012, and 11527801).

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