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Shear Horizontal Wave Transduction in Plates by Magnetostrictive Gratings

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Abstract

Shear horizontal waves are very useful in nondestructive evaluation applications because of their non-dispersive property. The objective of this research is to investigate frequency-tuned shear horizontal wave transduction in plates by using magnetostrictive nickel gratings. Since wireless energy conversion between magnetic energy and acoustic energy in magnetostrictive material can take place, the generation and measurement of waves by the magnetostrictive principle have recently received much attention. In this work, a grating-type magnetostrictive transducer was considered for SH wave transduction; waves can be effectively tuned at desired frequencies by changing grating size and distance. The present experiments showed that the bias field strength and grating width should be selected appropriately to avoid generating unwanted wave modes such as the S0-Lamb wave modes. It is also confirmed from experiments that the grating distance controls the center (or tuning) frequency of the grating transducer.

Keywords: SH Waves; Magnetastriction; Transducer; Grating

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1. Introduction

Most currently available acoustic-wave transducers are piezoelectric transducers (Gardner, et al., 2001) and electromagnetic-acoustic transducers (EMAT) (Ellis, et al., 2000; Murayama and Mizutani, 2002; Hirao, and Ogi, 2003). In this work, we consider alternative magnetostrictive transducers to de-velop an acoustic-wave transducer in plate structures. The proposed magnetostrictive transducer can have high energy and large displacement by increasing the number of encircling turns of the coil. The transducer can also generate desired shear horizontal wave modes by applying static magnetic bias field in the direction perpendicular to the wave propagation direction. This work is concerned with the development of a transducer generating and measuring ultrasonic waves in nonferromagnetic plates using the magnetostrictive effect (Jiles, 1995; Thompson, 1979).

Magnetostrictive transducers may be used more widely in nondestructive inspection applications and for material property inspection because they are cost effective and generate high-power waves without direct electric wiring to a magnetostrictive material. A magnetostrictive strip can be used for nonferromagnetic structures.

Because of its cost effectiveness, non-contact and high-power generation properties, the magnetostrictive technique has been successfully used in cylindrical waveguides (Lee and Kim, 2002; Kwun and Teller, 1994; Kim and Kim., 2006; Kim et al, 2005). However, the magnetostrictive technique has not been applied to plates until recently. Kwun and Bartels

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(Kwun, and Bartels, 1998) and Kwun et al.,(2002) suggested a transducer using magnetostrictive nickel strips for generating and measuring ultrasonic guided waves in plates. Cho *et al*. (2006) developed an ori-entation adjustable patch-type magnetostrictive trans-ducer for nonferromagnetic plates. However, these transducers generate waves of relatively low fre-quency and it is difficult to generate and measure waves centered at a required frequency. Unwanted S0-Lamb[1)] waves are also generated when shear horizontal waves are generated by the transduction methods mentioned above (Graff, 1975; Rose, 1999). To overcome the limitations of the existing magneto-strictive method, we consider grating-type magnetostrictive trans-ducers to effectively generate the SH waves in plates and to regulate the frequencies of the generated waves.

In our configuration, the nickel strips serve as both the magnetic path and the deforming elements. Therefore, the shape and size of the strips affect the characteristics of SH wave generation. These characteristics enable us to select the strip size yielding dominant SH wave modes without unwanted waves such as the S0 Lamb waves; in many appli-cations, pure SH wave generation is important be-cause nondispersive SH waves are very useful for signal processing and for long-range inspection. Our experiments showed that the strip width can be selected to generate signals having dominant SH waves.

In wave experiments, it is also important to enhance the frequency ranges of the generated SH waves and to regulate the frequencies of the required waves. To achieve this objective, the width of a nickel may be adjusted. However, as it is difficult to generate and measure the SH waves of higher frequencies by regulating the width of the nickel strip alone, we considered grating-type strips. It was possible to increase the magnitude of the generated signal by utilizing the relationship between the interval of the grating and the frequency. Several experiments were conducted to investigate the effect-tiveness SH wave generation and frequency characteristics of the proposed magnetostrictive grating-type transducer.

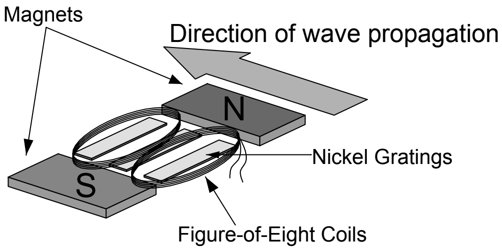
2. Experiments

2.1. Magnetostriction and magnetostrictive transducer

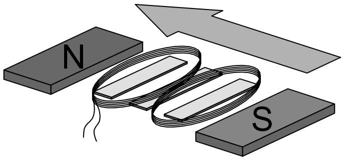
Magnetostrictive effect(jiles, 1995) refers to the coupling phenomena between mechanical stress and magnetic field. When a mechanical load is applied to a ferro-magnetic material, its magnetic field distribution changes, and vice versa. Because we use magnetic field, it is possible to generate and measure the ultrasonic waves wirelessly. Among various wave modes in plates, we are mainly concerned with SH waves because they are nondispersive and little influenced by the condition of the sample plate.

As shown in Figs. 1(a, b), the magnetostrictive transducers proposed in this investigation consist of several nickel strips, a coil surrounding the strips, and permanent magnets (Nd–Fe–B). To generate SH waves mode in the proposed setting, the static bias magnetic field produced by the permanent magnets must be perpendicular to the field generated by the coil (see Thompson (1979) for more detailed accounts). For comparison, Fig. 1(b) shows the S0 Lamb wave transducer, where the static bias magnetic field produced by the permanent magnets is parallel to the field generated by the coil.

When alternating current flows into the coil developing an alternating magnetic field, the strip is deformed by the magnetostrictive effect and ultrasonic waves are generated in the plates by the deformation of the nickel strip. Nickel strips possess a reasonable degree of magnetostriction. In our experiments, two transducers were used, one as a transmitter and the other as a receiver.



(a)



(b)

Fig. 1. A magnetostrictive transducer consisting of several nickel strips, permanent magnets, and coils.

[1)] The symbol Sn implies the $(n+1)^{th}$ symmetric Lamb mode. See Graff(1975) for the definition of the symbol.

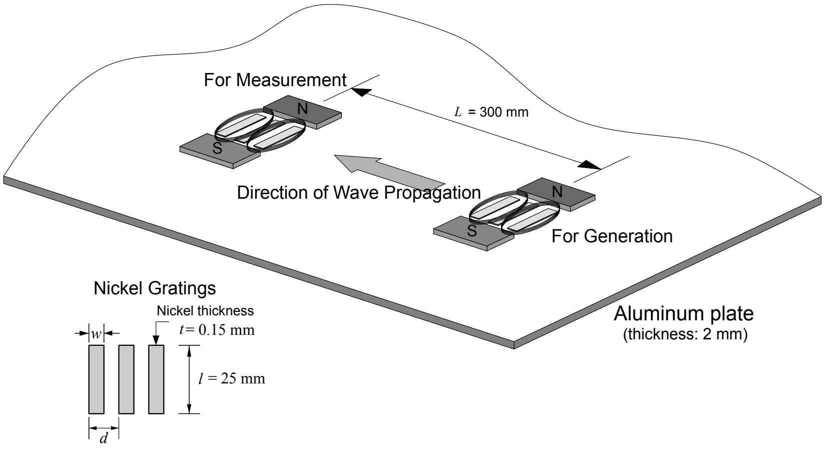


Fig. 2. Grating-type magnetostrictive transducers installed on an aluminum plate.

2.2. Experimental setup and results

Figure 2 shows the schematics of the experimental setup. Two transducers are used for SH wave experiments in a 2 mm thick aluminum plate. In each transducer, either single or multiple strips are bonded to the aluminum plate while sensing/actuating coils do not need to be in contact with the strips. The frequency-localized Gabor (or modulated Gaussian) pulses (Hong et al., 2005) were sent to a transmitter and the ge-nerated wave signals were measured by a receiver located at some distances away from the transmitter. By experiments, we investigated the following trans-ducer characteristics: the peak-to-peak magnitude ratio of the SH wave mode to the S0 Lamb wave mode, the frequency characteristics, and the effects of using multiple nickel strips, i.e. a grating.

As a basic experiment, a Gabor pulse having the center frequency of 140 kHz was sent to the transducer. Both the transmitter and the receiver are equipped with a single nickel strip having the dimension of l = 25 mm and w = 15 mm. Figure 3 (a) shows the measured wave signal by the receiver. Note that to generate and measure dominant SH waves, both the transmitter and the receiver used the same bias magnet arrangement of Fig. 1(a). By confirming that the experimentally measured wave speed is the same as the theoretical wave speed of the SH wave, the largest pulse in Fig. 3(a) is identified as the SH wave. The validity of the wave speed checking method was demonstrated in (Cho et al., 2006).

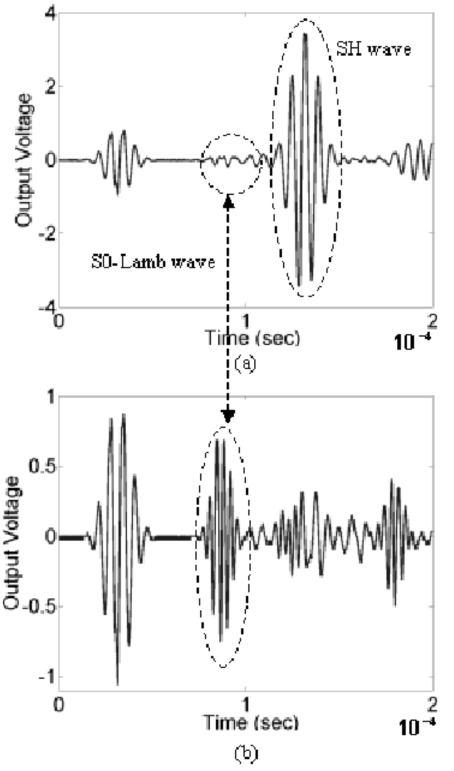
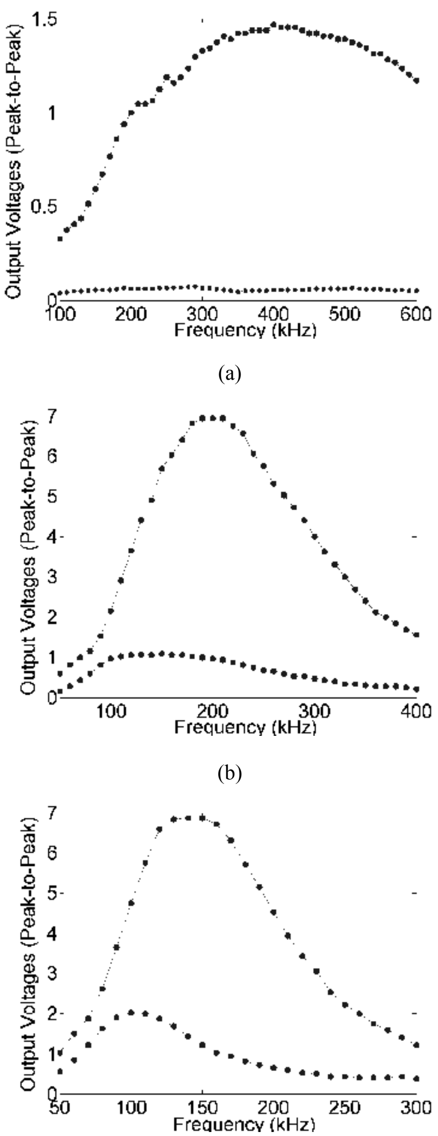


Fig. 3. (a) Signal when SH waves are generated and measured using the SH wave measuring configuration of Fig. 1(a). (b) Signal when SH waves are generated and unwanted S0 waves are measured using the S0-Lamb wave measuring configuration of Fig. 1(b).

Figure 3(a) also shows that some pulse traveling faster than the SH wave was picked up by the receiver. To identify what wave mode the pulse carries, another



(a)

(b)

(c)

Fig. 4. Peak-to-peak magnitudes of the measured SH waves and S0-Lamb waves by the transducer configuration proposed in Fig. 1(a) with the strip width equal to (a) 4 mm, (b) 8 mm, and (c) 15 mm (the strip length *l* = 25 mm).

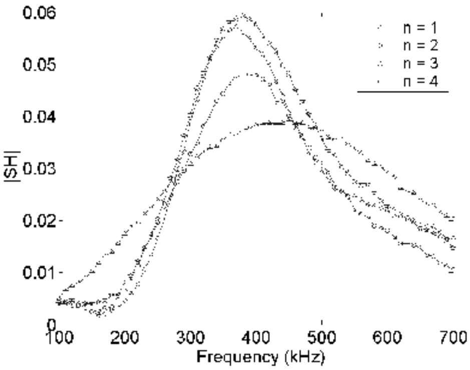


Fig. 5. The sensitivity and the frequency characteristics of the nickel gratings ($|\mathrm{SH}|$: the peak-to-peak magnitude of the SH wave, *n*: the number of the nickel strips used in the grating). The strip width w = 4 mm and grating distance d = 8 mm were fixed.

Table 1. The effect of the strip width (w) on the maximum transduction frequency (f) and the ratio $|\mathrm{SH/S0}|$.

width (w)	4 mm	8 mm	15 mm
f by experiment	400 kHz	200 kHz	135 kHz
f by Eq. (1)	398 kHz	199 kHz	106 kHz
$\lvert\mathrm{SH/S0}\rvert$	25	7.14	4.76

experiment was conducted by using a receiver having the configuration shown in Fig. 1 (b). This configuration is supposed to measure the S0 Lamb wave. The signal measured by the S0 Lamb-wave measuring transducer is shown in Fig. 3 (b). This result confirmed that a small unwanted S0-Lamb wave is also picked up by the transducer configuration of Fig. 1(a), which is designed mainly to generate and measure SH waves. Therefore, we should find a way to increase the relative ratio of the peak-to-peak magnitude of the SH wave to the peak-to-peak magnitude of the S0-Lamb wave. The relative ratio will be denoted by simply as |SH/S0| in the subsequent discussions.

Since the S0 Lamb wave involves the stretching deformation of the nickel strip in the direction of the wave propagation, the strip width w will affect |SH/S0|. Obviously, the maximum transduction frequency (f) will be also influenced by w. If $\lambda \approx 2w$ is substituted into the well-known formula,

$$f = c_T / \lambda \tag{1}$$

(c_T : SH wave speed in the aluminum plate; λ : the wave length)

the theoretical maximum transduction frequency can be predicted for a given width w. The experimental results obtained for varying widths of a single nickel strip are shown in Fig. 4. Figure 4 shows that both the SH waves and the S0-Lamb waves are measured simultaneously by the transducer configuration shown in Fig. 1 (a). The experimental data were collected at every 10 kHz and the maximum transduction frequency and the ratio |SH/S0| are summarized in Table I. The maximum transduction frequency is predicted fairly accurately by Eq.(1). As the strip width increases, both the ratio |SH/S0| and *f* decrease. In this respect, strips with smaller widths are preferred. However, the transducer output decreased and the frequency bandwidths became widened as *w* increased; therefore, one should consider a means to improve the transducer output (for the same input pulse magnitude) and to narrow the frequency bandwidth. Specifically, we considered a grating, i.e., a series of nickel strips.

Figure 5 shows the peak-to-peak magnitudes (|SH|) and the frequency characteristics of the measured SH waves by the grating. The peak-to-peak magnitude increased as the number of strips increased. The frequency bandwidth became narrowed, that is, the Q-factor was improved as the result of the grating. However, the transduction frequency localization did not improve much if the number of nickel strips became larger than 3. That is, only by using a grating with 3 strips, we can effectively localize the transduction frequency. The grating using three strips appears optimal because the use of too many strips deteriorates the spatial localization property of the transducer. In an earlier study conducted on a cylinder (Kim and Kim, 2006), the interval *d* between each strip, not the strip width *w*, is the main parameter to determine the maximum transduction frequency *f*. Therefore, by decreasing the interval, we can generate and measure higher-frequency shear waves.

3. Conclusions

The relative magnitudes of unwanted S0 Lamb waves are reduced as the strip width in the propagating direction is reduced. Hence, we can generate and measure pure SH waves better with narrower nickel strips. The frequency of the generated wave becomes higher as the width of the patch becomes Smaller. However, because it is difficult to generate frequency-localized waves with one narrow strip, grating transducer using a series of narrow nickel strips is required. The frequencies of generated waves can be regulated by using the grating. The interval between strips should coincide with the frequency-wavelength relationship.

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References

Cho, S. H., Sun, K. H., Lee, J. S. and Kim, Y. Y., 2006, “Guided Wave Transduction Experiment Using a Circular Magnetostrictive Patch and a Figure-of-eight Coil in Nonferromagnetic Plates,” *Applied Physics Letters*, 88, p. 224101

Ellis, K. A., van Dover, R. B., Klemmer, T. J. and Alers, G. B., 2000, “Magnetically Transduced Surface Aoustic Wave Devices,” *Journal of Applied Physics*, Vol. 87, pp. 6304~6306.

Gardner, J. W., Varadan, V. K. and Awadelkarim, O. O., 2001, Microsensors, *MEMS and Smart Devices, Wiley*: New York.

Graff, K. F., 1975, “Wave Motion in Elastic Solids,”Ohio-State Univ. Press.

Hirao, M. and Ogi, H., 2003, “EMATs for Science and Industry: Noncontacting Ultrasonic Measurements,” *Kluwer Academic Publishers*: London.

Hong, J. –C., Sun, K. H. and Kim, Y. Y., 2005, “The Matching Pursuit Approach Based on the Modulated-Gaussian Pulse for Efficient Guided-wave Damage Inspection,” *Smart Materials and Structures*, Vol. 14, pp. 548~560.

Jiles, D. C., 1995, “Theory of the Magnetomechanical Effect,” *Journal of Physics. D*, Vol. 28, pp. 1537~1546.

Kim, I. K. and Kim, Y. Y., 2006, “Wireless Frequency-tuned Generation and Measurement of Torsional Waves using Magnetostrictive Nickel Gratings in Cylinders,” *Sensors and Actuators A*, Vol. 126, pp. 73~77.

Kim, Y. Y., Park, C. I., Cho, S. H. and Han, S. W., 2005, “Torsional Wave Experiments with a New Magnetostrictive Transducer Configuration,” *Journal of Acoustical Society of America* Vol. 117, pp. 3459~3468.

Kwun, H. and Bartels, K. A., 1998, “Magnetostrictive Sensor Technology and Its Applications,” *Ultrasonics,* Vol. 36, pp. 171~178.

Kwun, H. and Teller, C. M., 1994, “Magnetostrictive Generation and Detection of Longitudinal, Torsional, and Flexural Waves in a Steel Rod," *Journal of Acoustical Society of America*, Vol. 96, pp. 1202~1204.

Kwun, H., Kim, S. Y. and Crane, J. F., 2002, Method and Apparatus Generating and Detecting Torsional Wave Inspection of Pipes or Tubes US Patent No. 6,429,650 B1

Lee, H. C. and Kim, Y. Y., 2002, "Wave Selection using a Magnetomechanical Sensor in a Solid Cylinder," *Journal of Acoustical Society of America*, Vol. 112, pp. 953~960.

Murayama, R. and Mizutani, K., 2002, "Conventional Electromagnetic Acoustic Transducer Development for Optimum Lamb Wave Modes," *Ultrasonics,* Vol. 40, pp. 491~495.

Rose, J. L., 1999, "Ultrasonic Waves in Solid Media," Cambridge Univ. Press: New York.

Thompson, R. B., 1979, "Generation of Horizontally Polarized Shear Waves in Ferromagnetic Materials Using Magnetostrictively Coupled Meander-coil Electromagnetic Transducers," *Applied Physics Letters*, Vol. 34, pp. 175~177.