DEVELOPMENT OF ACOUSTIC WAVE FILTERS BY USING MAGNETOSTRICTIVE NICKEL GRATINGS

Ik Kyu Kim[1] and Yoon Young Kim[1]
[1]Seoul National University, Seoul, Korea

Abstract: Acoustic wave devices have gained enormous interest for sensor applications. In the current practice, the surface acoustic waves are usually generated and measured by piezoelectric transducers. In this work, however, we propose to generate the acoustic waves by using a magnetostrictive transducer using magneticstrictive nickel strip gratings and a sensing coil. The coil encircling the gratings converts the magnetic flux change induced by the strain of the strips into voltage change, and vise versa. The main motivation using magnetostrictive transducers, not piezoelectric transducers, is that the wave generation and measurement can be achieved without direct wiring to the magnetostrictive nickel gratings. In addition, the transducer can be cost-effective. It is shown that the grating distance can be so tuned to the center frequency that narrow-band wave signals can be effectively excited and measured.

Introduction: Most of currently-available acoustic wave filters use piezoelectric transducers(1). In this work, however, we will consider the possibility of using alternative magnetostrictive transducers to develop an acoustic wave filter. The magnetostrictive effect refers to the coupling phenomena between the mechanical field and the magnetic field. When a mechanical load is applied to a ferromagnetic material, its magnetic field distribution changes, and vice versa(2-4). When piezoelectric materials are used for acoustic wave filters, they are arranged in a inter-digital type. However, we arrange the magnetostrictive nickel strips in a grating type because of the different mechanics involved. Obviously, the grating distance affects the center frequency of the developed acoustic filter. To investigate the frequency characteristics of the proposed magnetostrictive grating-type transducer, several experiments were conducted.

The main motivation to use the magnetostrictive materials is due to the possibility of generating and measuring waves without direct electric wiring to the materials(5-6). In this work, the possibility to tune the desired frequency by the magnetostrictive grating distance will be investigated. The actual experiments were conducted on aluminum pipes where torsional waves were generated by the proposed approach. The suggested acoustic filter consists of several nickel strips, a coil surrounding the strips and some measurement equipment. Nickel is used as a magnetostrictive material in the present application. Since nickel strips are quite flexible and possess a reasonable degree of magnetostriction, they can be bonded on the curved pipe surface.

In the present work, experiments were conducted on an aluminum pipe where the torsional wave was generated and measured by the proposed transducer. Since torsional waves are non-dispersive(7-8), it is easy to process the measured wave signals. Although only the torsional waves in a pipe were investigated, the idea using the nickel grating can be extended to the design of surface acoustic wave filters.

Results: 1. Sensing mechanism by the magnetostrictive transducer

Figure 1 shows nickel strips attached to a pipe. Two magnets are installed in order to produce the magnetic flux along the nickel strip direction. The motivation to use the magnets will be explained later. Figure 2 shows the schematic diagram of the experimental configuration.

As indicated in Fig. 1, the magnetostrictive transducer consists of nickel strips, magnets and a solenoid coil. If stress is developed in the region of a pipe where the solenoid coil encircles, the stress causes the change in the magnetic field of the nickel strip. Then the change will be picked up by the solenoid coil as the voltage change. The solenoid coil serves both as the signal transmitter and receiver. To generate torsional waves, an electric pulse is sent through the solenoid coil(9-11).

ADDRESS CORRESPONDENCE TO:
Abstract Number: 487
Name: Ik Kyu Kim
Phone: 82-2-880-1688
Fax: 82-2-872-5431
E-mail: kik@idealab.snu.ac.kr

(a) (b)

Fig. 1. Nickel strips attached to a pipe:
(a) Nickel gratings (b) Nickel gratings under a bias magnetic field

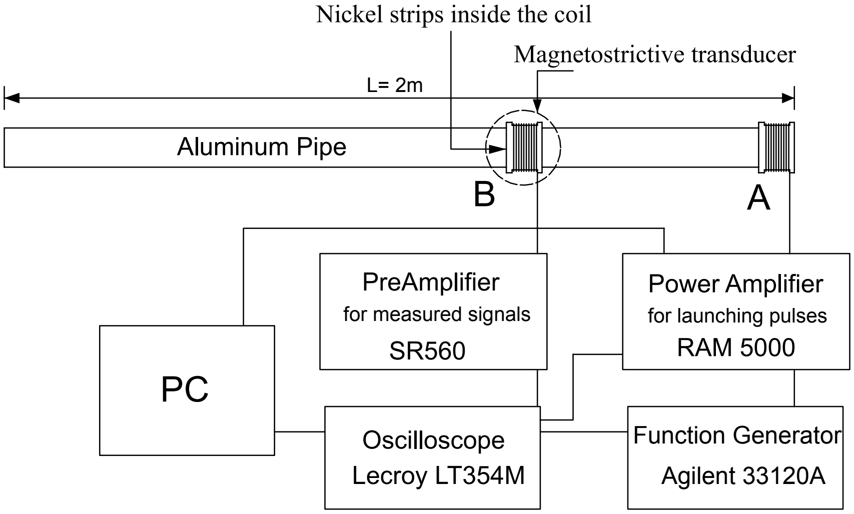


Fig. 2. The schematic diagram of the experimental setup

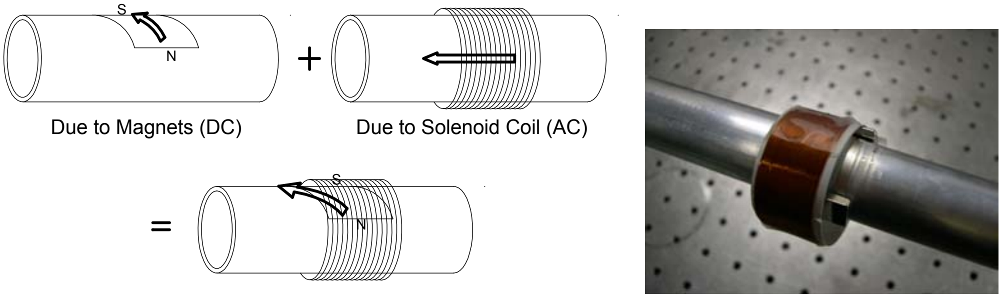


Fig. 3. Development of torsional waves

The mechanics of the torsional wave generation by a single nickel illustrated in Fig. 3 is based on Kwun's approach(12). The permanent magnets induce a static bias magnetic field in the circumferential direction. When alternating current is sent through the solenoid coil, an alternating magnetic field pointing in the axial direction is also developed on the nickel strips as shown in Fig. 3. The resulting magnetic field causes the deformations of the nickel strips approximately in the direction of 45° relative to the pipe axis.

2. Arrangement of nickel patches for filter application

In a piezoelectric surface acoustic wave filter, its center frequency is determined by the distance of IDT (inter-digital transducer) as in Fig. 4(a). In a magnetostrictive transducer, the distance λ between each grating (Fig. 4(b)) should be the wavelength of the wave having the center frequency. Figure 5 compares the deformation patterns of the piezoelectric transducer and the magnetostrictive transducer. It is difficult to deform the strips at the alternating phase with the magnetostrictive transducer (i.e, one strip compressed, the next strip elongated), the characteristic wavelength of the wave generated by the transducer will be determined only by the grating distance.

Using the nickel grating distance of λ and considering the non-dispersive torsional wave mode, one can estimate the center frequency f^c of the magnetostrictive acoustic filter from Eq. (1):

$$f^c = \frac{c}{\lambda} \tag{1}$$

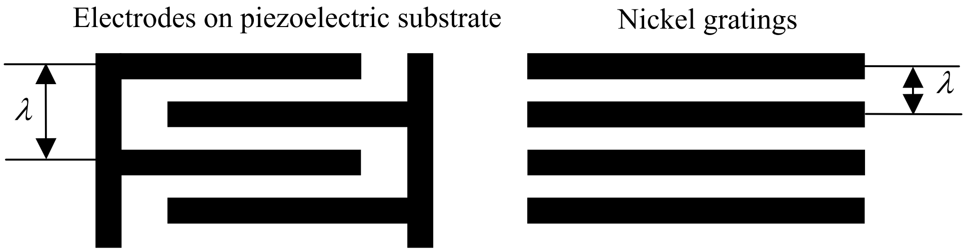
where c is the wave speed of the non-dispersive torsional mode.

3. Verification

Two sets of experiments with different grating distances λ=6 mm and λ=8 mm were conducted to examine the frequency response of the magnetostrictive grating-type acoustic filter. Figure 6 shows the dimensions of the nickel strips and the pipe. The following Gabor-type pulse signals *s(t)* were sent through a solenoid coil at A and measured by the solenoid coil at B.

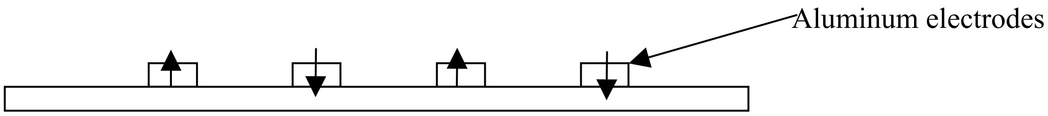
$$s(t) = \frac{1}{(\sigma^2 \pi)^{1/4}} \exp\left(\frac{-t^2}{2\sigma^2}\right) e^{i\eta t} \tag{2}$$

where $\sigma\eta = 5.0$ was used(13), and η is the center frequency of the pulse. The center frequencies were varied from 200 kHz to 1000 kHz and the ratios between the peak-to-peak magnitude of the transmitted signal at A and the peak-to-peak magnitude of the measured signal at B were plotted in Fig. 7.

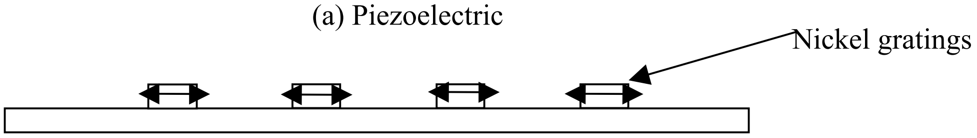


(a) Piezoelectric transducer (b)Magnetostrictive transducer

Fig. 4. The shapes of piezoelectric transducer and magnetostrictive transducer



(a) Piezoelectric



(b) Magnetostrictive

Fig. 5. Deformation patterns of the piezoelectric transducer and the magnetostrictive transducer

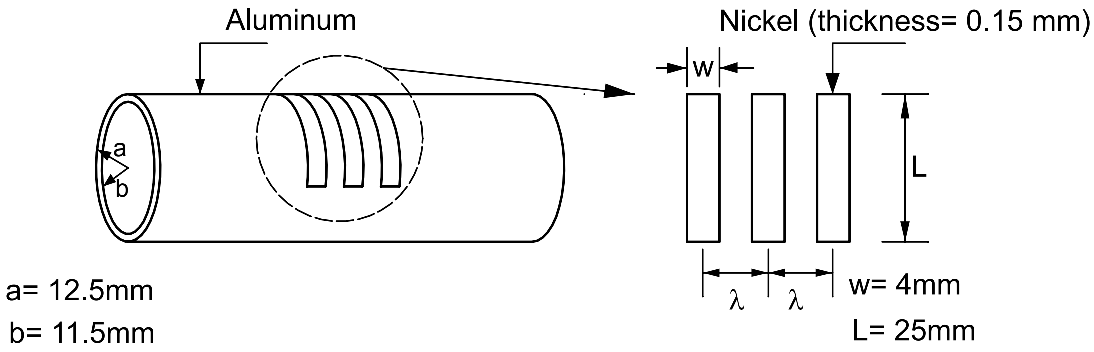
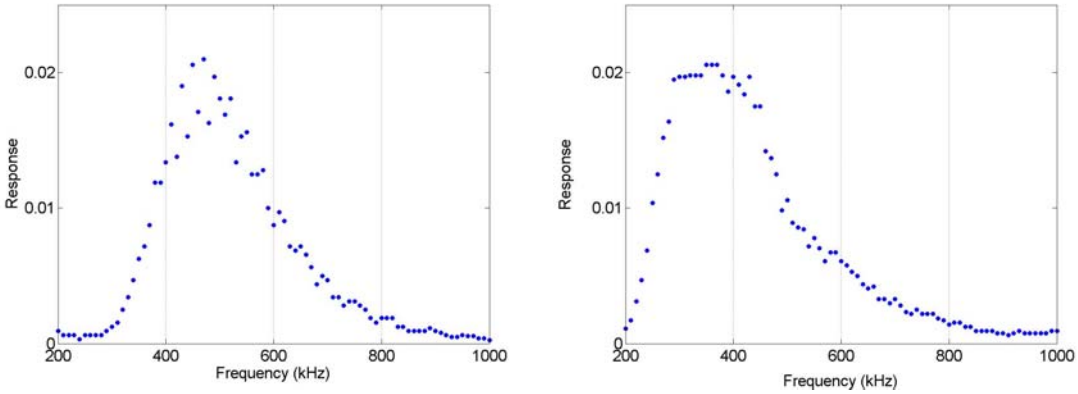


Fig. 6. The dimensions of the nickel strips and the pipe



(a) λ=6 mm (b) λ=8 mm

Fig. 7. The frequency characteristics of the proposed nickel-grating type transducer

Using Eq. (1) and the torsional wave speed c= 3125 m/sec in the aluminum pipe, the theoretical value of f^{c}_{theory} are calculated as

$$f^{c}_{theory} = 520 \text{ kHz for } \lambda = 6 \text{ mm} \tag{3a}$$

$$f^{c}_{theory} = 390 \text{ kHz for } \lambda = 8 \text{ mm} \tag{3b}$$

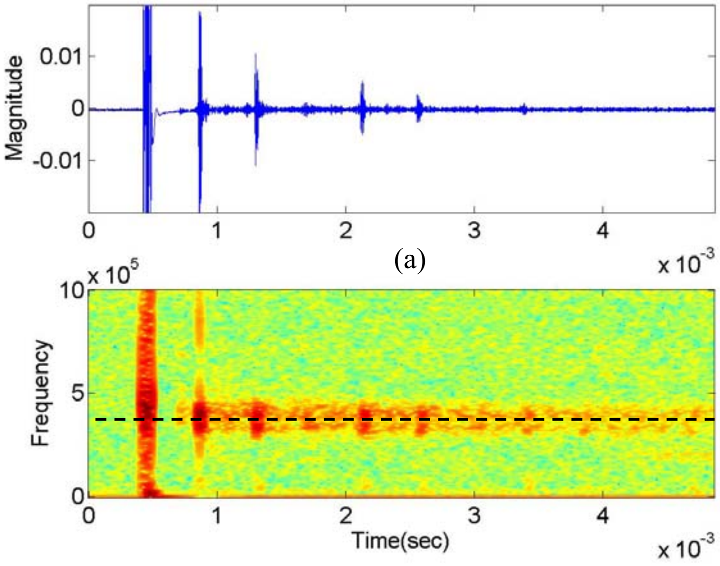
These values are compared favorably with the experimental values that can be extracted from Fig. 7:

$$f^{c}_{experimental} = 490 \text{ kHz for } \lambda = 6 \text{ mm} \tag{4a}$$

$$f^{c}_{experimental} = 380 \text{ kHz for } \lambda = 8 \text{ mm} \tag{4b}$$

Figure 8 shows a typical signal measured for λ=8 mm. The center frequency of the Gabor pulse in Eq. (4b) was 380 kHz. From Fig. 8(b), one can see that the energy of the Gabor pulse is centered at the frequency of 380 kHz. One can also observe the non-dispersive characteristics of the torsional wave (from the vertical lines in Fig. 8(b)).

Conclusions: In this paper, the possibility of developing an acoustic wave filter by using magnetostrictive transducers was examined. In particular, a nickel grating-type magnetostrictive transducer was proposed as a new acoustic wave filter. Because the elastic deformation of nickel gratings can be developed by solenoid coils encircling the gratings, the elastic wave generation and measurement were achieved without any direct wiring to the nickel gratings. The frequency characteristics of the proposed acoustic wave filter checked on aluminum pipes were quite satisfactory.



(a)

(b)

Fig. 8. The measured signal for λ=8 mm with η= 380 kHz,
(a) Time signal, (b) The short-time Fourier transform of the time signal (a).

References:

1. J. W. Gardner, V. K. Varadan and O. O. Awadelkarim, Microsensors, MEMS and Smart Devices, (Wiley, New York, 2001).
2. D. C. Jiles, "Theory of the magnetomechanical effect," J. Phys. D: Appl. Phys., 28, 1537-1546, (1995).
3. J. P. Joule, "On the effect of magnetism upon the dimensions of iron and steel bars," Phi. Mag. III, 30, 76, (1847).
4. E. Villari, "Change of magnetization by tension and by electric current," Ann. Phy. Chem., 126, 87-122, (1865).
5. H. C. Lee and Y. Y. Kim, "Wave selection using a magnetomechanical sensor in a solid cylinder," J. Acoust. Soc. Am., 112(3), 953-960, (2002).
6. Y. Y. Kim, S. H. Cho, and H. C. Lee, "Application of magnetomechanical sensors for modal testing," Journal of Sound and Vibration, 268(4), 799-808, (2003).
7. K. F. Graff, Wave Motion in Elastic Solids, (Ohio-State Univ. Press, 1975).
8. J. L. Rose, Ultrasonic Waves in Solid Media, (Cambridge Univ. Press, New York, 1999).
9. H. Kwun and C. M. Teller, "Magnetostrictive generation and detection of longitudinal, torsional, and flexural waves in a steel rod," J. Acoust. Soc. Am., 96(2), 1202-1204, (1994).
10. H. Kwun and K. A. Bartels, "Magnetostrictive sensor technology and its applications," Ultrasonics, 36, 171-178, (1998).
11. H. Ohzeki and A. Mashine, H. Aoyama, and I. Inasaki, "Development of a magnetostrictive torque sensor for milling process monitoring," Journal of Manufacturing Science and Engineering, 121, 615-622, (1999).
12. H. Kwun, "Method and apparatus generating and detecting torsional wave inspection of pipes or tubes," U.S. Patent 6429650 B1, (2002).
13. Y. Y. Kim and E. H. Kim, "Effectiveness of the continuous wavelet transform in the analysis of some dispersive elastic waves," J. Acoust. Soc. Am., 110(1), 86-94 (2001).