최적 요크를 갖는 자기변형 그레이팅을 이용한 고출력 주파수 튜닝 평판 SH 파 발생

Magnetostrictive Grating with an Optimal Yoke for Generating High-Output Frequency-Tuned SH Waves in a Plate[*]

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Key Words : Magnetostrictive grating, SH wave, Yoke, Topology optimization, Magnetic field

ABSTRACT

The objective of this presentation is to introduce a recent development of a magnetostrictive grating technique using an optimal yoke to efficiently generate and measure SH (Shear-Horizontal) waves in a plate. Gratings are effective means to generate frequency-tuned waves, but the gap between magnetostrictive gratings inevitably obstructs magnetic flow. Because magnetic field is the main physical quantity to actuate and sense ultrasonic waves, the transducer performance is most significantly influenced by the magnetic field distribution in the strips. Thus, wave transduction efficiency can be substantially improved if better magnetic flow is formed in the strips. To improve the efficiency, the topology optimization method was used to determine an optimal yoke configuration. A series of experiments on an aluminum plate were conducted using a grating with and without the designed yoke; when the yoke was used, the signal outputs increased up to 60 %.

1. INTRODUCTION

In comparison with popular piezoelectric ultrasonic wave transduction mechanism [1], the main advantages of using magnetostrictive transducers are wireless transduction and cost-effectiveness. Because magnetostriction [2] is the coupling phenomenon between mechanical deformation and magnetic field change, no direct wiring to magnetostrictive material [3-6] is necessary unlike in piezoelectric transducers. In this investigation, a magnetostrictive grating made of nickel is used as an alternative wave transduction mechanism for the generation of ultrasonic SH (Shear-Horizontal) waves in a plate. The first branch of SH waves is preferred in nondestructive evaluation of a plate because it is the only non-dispersive mode [7, 8]. The wave speed of a non-dispersive wave mode is independent of frequencies so that any pulse generated within the non-dispersive mode preserves its shape during wave propagation

Fig. 1 (a) shows an experimental setup used for SH wave transduction on an aluminum plate by magnetostrictive nickel gratings. Figures 1 (b) and (c) schematically illustrate a single nickel strip transducer and a nickel grating transducer, respectively. Note that the magnetic transducer in Fig. 1(c) consists of a nickel grating, permanent magnets providing static bias magnetic field and a set of coils supplying or sensing time-varying field.. The strip in Fig. 1(b) or the grating in Fig. 1(c) must be bonded onto the plate for ultrasonic wave transduction. In Fig. 1(b), Symbol ① denotes the static bias field direction applied to the nickel strip while Symbol ②, the dynamic field direction parallel to the z axis. The dynamic field is generated by two nearby coils. The coils perform both as actuating and sensing elements. To generate SH waves, the direction of the static bias magnetic field must be orthogonal to the direction of the dynamic magnetic field [9].

When a grating as in Fig. 1(c) was used, the center frequency of generated waves could be predicted by the

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[*] The main development of this work will appear in Sensors Actuators A (2007), "I.K. Kim, W. Kim, Y. Y. Kim, Magnetostrictive Grating with an Optimal Yoke for Generating High-Output Frequency-Tuned SH Waves in a Plate."

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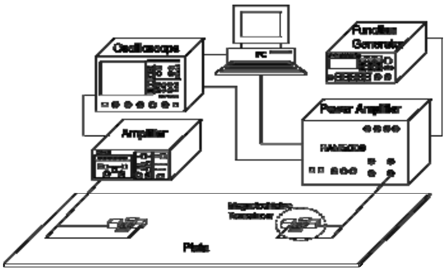
following simple relation:

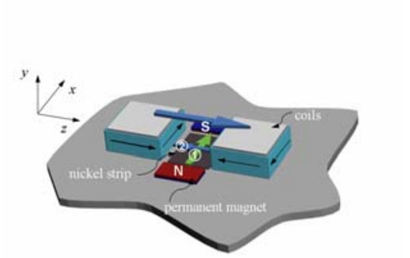
$$f_c = c_S / \lambda \tag{1}$$

In Eq. (1), f_c, c_S and λ denote frequency, shear wave speed, and wavelength. Equation (1) indicates that the center frequency can be controlled by the interval of a grating d if d is equal to λ. When lower center frequencies are needed, larger values of d must be used. In this case, the signal output becomes smaller because larger intervals make it more difficult for the magnetic field to flow across grating strips. As a result, the magnitude of the magnetic flux density in the strips will decrease and the magnetic field among the strips will be less uniform. So, we considered introducing a magnetic yoke to improve magnetic flow across the strips of the grating.

To find an optimal magnetic yoke configuration, the method of topology optimization developed for magnetic systems [10, 11] may be used. Because the method does not require a baseline design, it can be useful when no initial design is available. Though the optimization procedure for magnetic systems has been established, the problem is how to set up the present yoke design problem.



(a)



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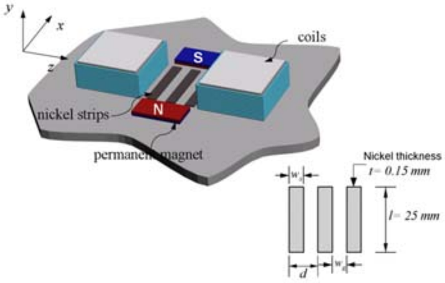
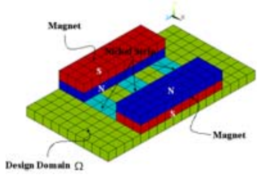


(c)

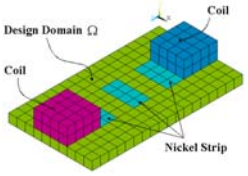
Fig. 1. (a) Experimental setup for SH wave transduction by magnetostrictive nickel grating transducers in a plate, (b) Schematic diagram of a single nickel strip transducer, (c) Schematic diagram of a nickel grating transducer.

2. MAGNETIC YOKE DESIGN

The illustrations on the left and right sides in Fig. 2(a) show three-dimensional finite element models constructed for the topology optimization of a yoke configuration to improve magnetic flow. To facilitate yoke design, optimization is carried out separately for each of the two magnetic field directions, and the two results will be combined into a final optimal yoke shape. The two-dimensional view of the illustrations without the elements denoting coils or permanent magnets is shown in Fig. 2(b). The region meshed by finite elements in Fig. 2(b) represents the design domain where a magnetic yoke can be located. The shaded region marked by “nickel strips” is not a part of the design domain because the region is the area where nickel strips are to be bonded on a test plate (not shown). Note that the yoke will be simply placed on a test plate, not bonded to it because it is used only as a magnetic flow path. If it was bonded, wave modes other than SH wave modes would be generated. The yoke will be made of nickel, the same material used for strips.

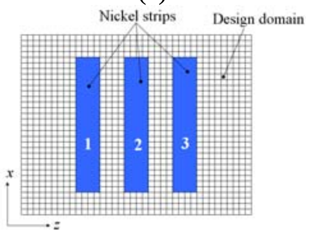


For magnetic field maximization in the x direction



For magnetic field maximization in the z

(a)



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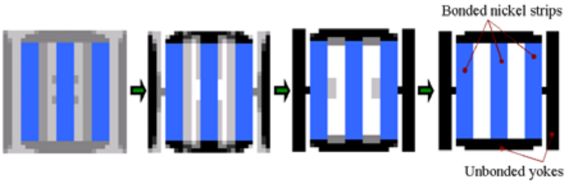
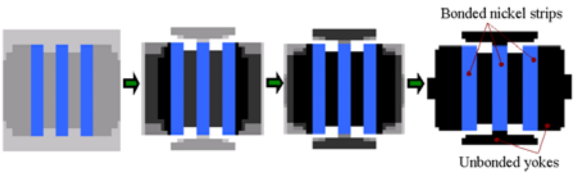
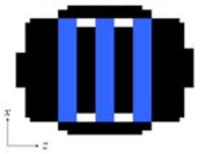


For the maximization of f_x



For the maximization of f_z

(c)



(d)

Fig. 2. (a) Three-dimensional finite element models used to find optimal yoke configurations by the topology optimization, (b) Two-dimensional view of the finite element models in (a) without showing coils and permanent magnets, (c) Intermediate and final yoke configurations obtained by solving Problems (A) and (B) by the topology optimization method, (d) Final yoke configuration (drawn in black)

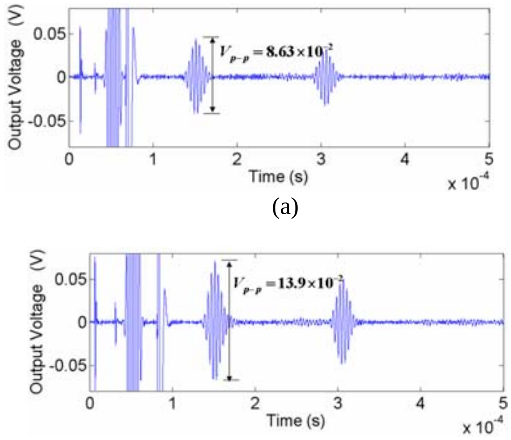
The detailed topology optimization procedure is not given here, but the optimized results in Fig. 2(c) shows intermediate and final yoke configurations obtained by the topology optimization method. As shown in Fig. 2 (c), the optimized yoke configurations are made of separate pieces. The optimized yoke configurations for the *x* and *z* directions are different as may be expected, but a single yoke configuration must be chosen because the magnetic fields in the *x* and *z* directions are applied simultaneously to the nickel strip for actual situations. Thus, the union of the two optimized yoke configurations is selected as the final yoke configuration. It is illustrated in Fig. 2(d).

3. Experimental verifications

Fig. 3 shows the effects of using the yoke of Fig. 2(d) on the signal output by the grating transducer; referring to the experimental setup in Fig. 1(a), the energy-centralized Gabor pulse [12] with the center frequency of f_c =240 kHz was sent to one of the two transducers while the other transducer picked up the wave transmitted along the test plate. The first pulse denotes the wave directly from the actuating transducer to the sensing transducer, and the second pulse, the reflected wave from the plate end. As shown in Fig. 4, shows that the use of the yoke increases the peak-to-peak output voltage V_{p-p} from 8.60×10^{-2} V to 13.9×10^{-2} V, which amounts to 62% increase. Experimental results performed for three different grating intervals are shown in Fig. 4: *d* = 8 mm (*w* = 4 mm), *d* = 10 mm (*w* = 5 mm), *d* = 12 mm (*w* = 6 mm). The Gabor pulses were transmitted at intervals of 20 kHz from 100 kHz to 600 kHz. The findings from these experiments can be summarized as:

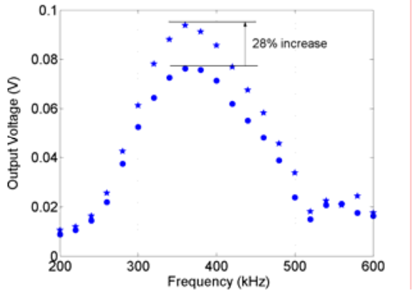
Even if the yoke is installed to the grating, the relation (Eq. (1)) between the center frequency and the grating distance holds. For *d* = 8 mm, 10 mm, and 12 mm, $f_c^{\text{experiment}}$ = 360 kHz, 280 kHz and 240 kHz were obtained. These frequencies compare favorably with $f_c^{\text{theory}}\big|_{\text{by Eq. (1)}}$ = 387 kHz, 310 kHz and 258 kHz.

For all tested values of *d*, the magnitudes of the signals measured by the grating transducer having the optimized yoke increased at all driving frequencies. For larger grating intervals, the effect of the yoke installation is more profound.

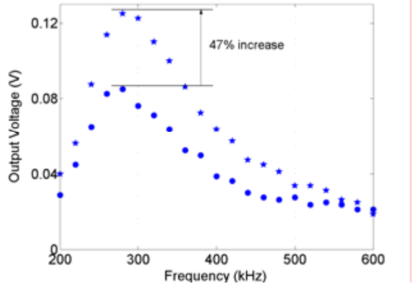


(b)

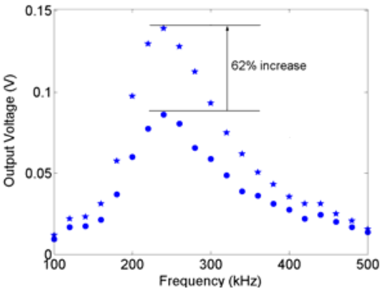
Fig. 3 (a) The signal by the transducer with only the grating (b) the signal by the transducer with the grating and the designed magnetic yoke (grating distance *d* = 12 mm, center frequency f_c = 240 kHz)



(a) *d* = 8 mm



(b) *d* = 10 mm



(c) *d* = 12 mm

Fig. 4 Peak-to-peak voltage output by the nickel grating on the aluminum plate with (★) and without (•) the optimized yoke. (a) *d* = 8 mm, (b) *d* = 10 mm and (c) *d* = 12 mm.

4. Conclusions

The use of a magnetic yoke was proposed to improve the magnetic flow field around grating strips. The yoke configuration problem was set up as a topology optimization problem. The optimized yoke was shown to play a significant role in increasing the transducer output especially for large grating intervals.

ACKNOWLEDGEMENTS

This research was supported by the National Creative Research Initiatives Program (Korea Science and Technology Foundation grant No. 2006-033) contracted through the Institute of Advanced Machinery and Design at Seoul National University.

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