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Under Water Sonar Transducer Using Terfenol-D Magnetostrictive Material

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In this work we have constructed an under water sonar transducer using Terfenol-D rod employing open magnetic circuit. Normally Sonar transducer using Terfenol-D was designed under closed magnetic flux return path, and permanent magnet for dc bias marnetic field, but high magnetic field should be applied to the transducer coil for high sound power and it brings temperature increase inside of the transducer. To improve this heat dissipation problem, we have designed an open magnetic circuit type transducer and we can get 200 dB (re. 1 μPa @ 1 m) sound power for the input power of 650 VA.

1. Introduction

Using magnetostrictive materials, we can convert magnetic energy to mechanical energy or vice versa. The magnetostriction of the Terfenol-D is 1.8×10^{-3} at moderate magnetization levels at room temperature, and this strain is 10 times larger than PZT. This point of view, Terfenol-D is an excellent material for low frequency sonar transducer application. But higher frequency, due to the eddy current effect [1], PZT is more effective. Terfenol-D is an attractive material for an active vibration supression and an under water sonar transducer, and mostly developed devices using Terfenol-D have closed magnetic flux return path and permanent magnet for dc bias magnetic field [2]. To obtain high sound power, high magnetizing current is required and this brings temperature increasing inside of the transducer.

In this work, we could construct an open magnetic circuit type of under water sonar transducer because the relative permeability of the Terfenol-D rod is about 50 and the demagnetizing effect becomes relatively small [3]. Therefore we could improve the heat dissipation problem due to the high magnetizing current using cooling oil.

2. Construction of the Transducer

For the construction of sonar transducer, we have used Terfenol-D rod of 100 mm in length and 6 mmϕ in diameter which was produced by ETREMA. Fig. 1 shows the constructed transducer. It consist of non-magnetic stainless steel housing, brass-bolt at the tail mass for controlling compressive pre-stress to the Terfenol-D rod, planer type spring of 0.8 mm in thickness using sts-304 material at the head part to apply mechanical pre-stress, solenoid of 567 turns enameled copper wire of 1.2 mmϕ in diameter for appling magnetic field to the Terfenol-D rod, and sound radiating aluminum plate of 130 mmϕ in diameter at the head. The mechanical pre-stress was set at a suitable compressive stress to obtain for the largest strain at the head.

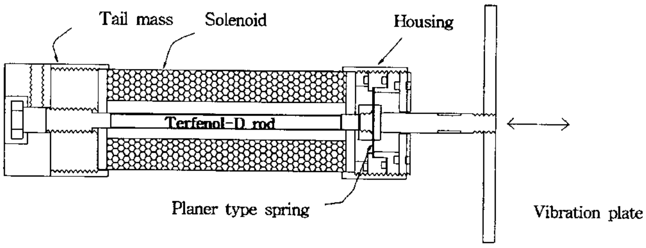

Fig. 1. Constructed open magnetic circuit type transducer.

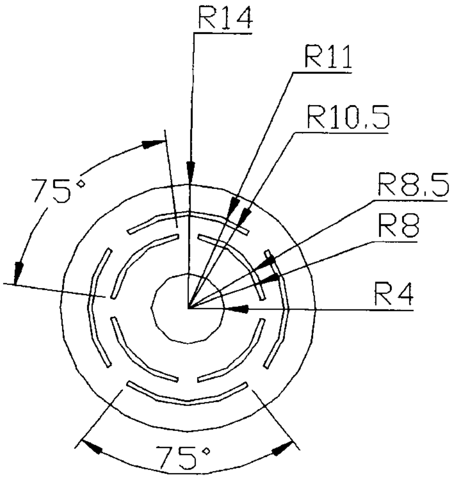

Fig. 2. Planer type spring for pre-stressing the Terfenol-D rod.

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When the mechanical pre-stress is appled to the Terfenol-D rod, the prestress direction should be the longitudinal direction of the Terfenol-D rod. If the mechanical pre-stress direction was the transverse direction, Terfenol-D rod broken easily during test. So we employed the planer type spring as shown in Fig. 3 that is more stable than spiral type spring. The spring constant of the planer type spring was 2.5×10^5 N/m.

3. Experiments

After construction of the transducer, we have measured λ-H characteristics. Fig. 3-(a) shows the λ-H loop under without dc bias mafnetic field, and Fig. 3-(b) for λ-H loop under dc bias magnetic field of 47 kA/m. From this λ-H loop measurements, we have conformed that the trasducer was properly constructed.

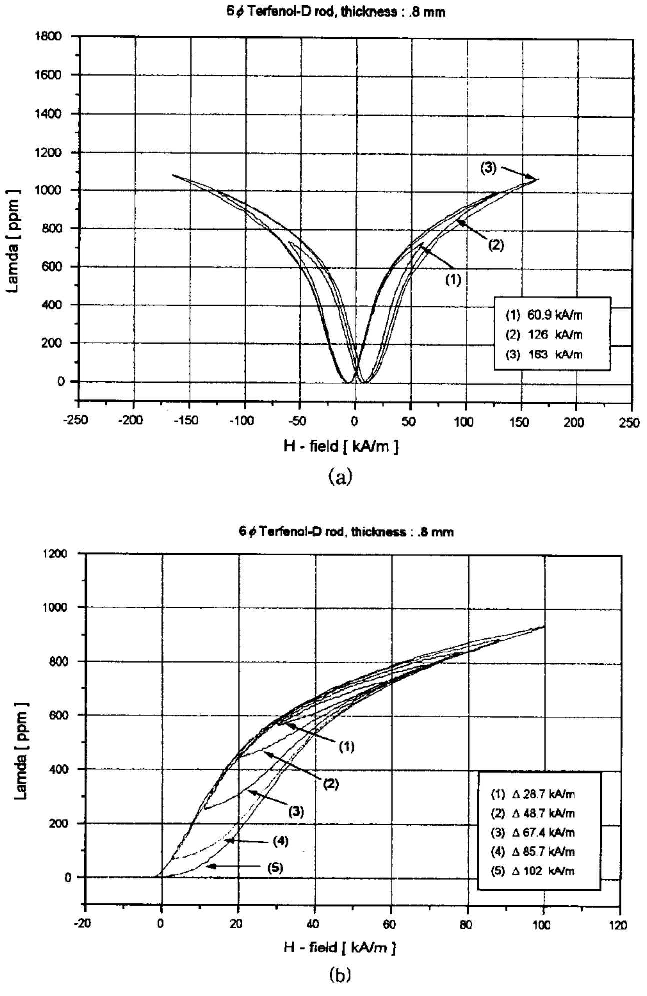
For the transducer operation, there are two possible methods. One is operation under ac driving current without dc bias mafnetic field as shown in Fig. 3-(a). In this case, frequency of radiated sound is double of the ac driving current frequency, but wave form of sound is highly distorted. The other operation is ac driving current with dc bias magnetic field as shown in Fig. 3-(b), and frequency of radiated sound is the same as the frequency of ac driving current. In this work, we have operated the transducer under proper dc bias magnetic field

For the measurement of radiation power of the transducer, we employed two methods. One for frequency ranging from 10 Hz to 100 Hz, we used the LVDT (Linear Variable Differential Transducer) for displacement measurement as shown in Fig. 4. The other for frequency ranging 100 Hz to 5 kHz used the PZT type accelerometer as shown in Fig. 5. Fig. 6-(a) and Fig. 6-(b) show the λ-H loops at ftrquncy of 10 Hz and 100 Hz respectively. From this λ-H loop, we can see that frequency becomes higher, hysteresis of λ-H loops becomes higher due to the eddy current effect of terfenol-D rod. For higher frequency operation, laminated structure of Terfenol-D is required to reduce eddy current effect. Data from these method are converted to the displacement and calculated the sound radiation power P_S and sound pressure level P_L using the fellowing equations [4].

$$P_s=4\pi^2b^2f^2z_c\xi^2\left[1-\frac{J_1(2kb)}{kb}\right] \tag{1}$$

$$P_L=20\log\left(\frac{2\pi^2b^2f^2\rho_0\xi}{r^2\times10^{-6}}\right) \tag{2}$$

Where b is radius of the radiation head, f modulation frequency, z_c characteristic impedance of transmit material, ξ displacement, k propagation constant, ρ_0 density of the transmit material, and r distance from the radiating head to



(a)

(b)

Fig. 3. Dc λ-H characteristics of the constructed transducer.

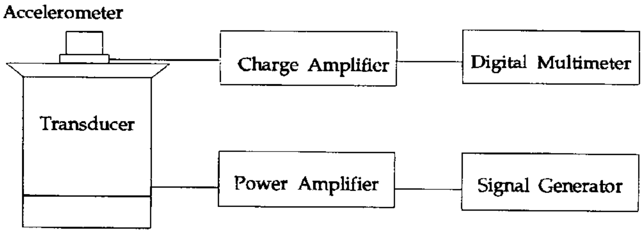


Fig. 4. Schematic diagram for the measurement vibration amplitude of the transducer for frequency ranging from 10 Hz to 100 Hz.

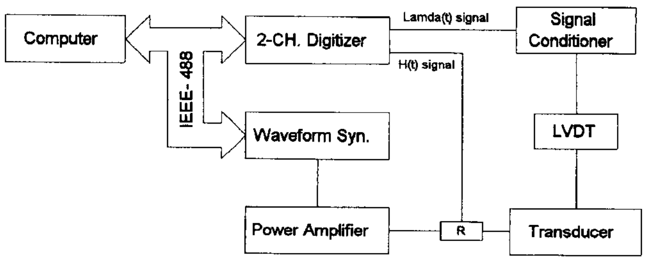
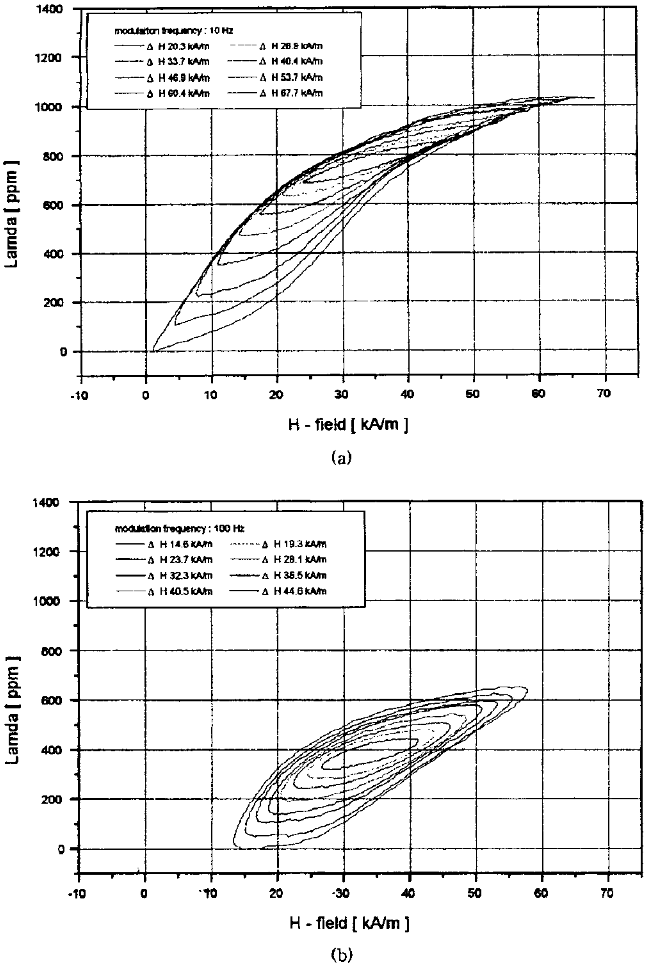


Fig. 5. Schematic diagram for the measurement vibration amplitude of the transducer for the frequency ranging from 100 Hz to 5 kHz.



(a)

(b)

Fig. 6. λ-H loops of the constructed transducer at 10 Hz and 100 Hz driving frequency.

the measurement position.

For driving electric power to the transducer, we have applied dc-biased ac current to the solenoid using power amplifier (Techron 7560) and oscillator

4. Results and Discussion

Fig. 7 shows the radiation power and the sound level under driving frequency ranging from 10 Hz to 5 kHz at constant input power of 5 VA with dc bias field 35 kA/m. Sound power was increased when frequency was increased and reached at maximum at resonance frequency after that decreased. The resonance frequency of the constructed transducer was 2.1 kHz, This is relatively good agreement to the calculated mechanical resonance frequency $f_r = \frac{1}{2\pi}\sqrt{\frac{k\left(1+\frac{m}{M}\right)}{m}} \fallingdotseq 2.5$ kHz, where m head mass, M tail mass, k coupling stiffness.

For the diameter of 6 mmϕ Terfenol-D, strain was decreased when frequency was increased under constant input power as shown in Fig. 8. we expect that this is mainly due to the eddy current effect. From Fig. 8 and equation (1), if we could reduce the eddy current effect using laminated structure of Terfenol-D, we could increase sound radiation power in high frequency range. Fig. 9 shows that driving input power was increased from 6 VA to 650 VA at the resonance frequency of 2.1 kHz. We could obtain maximum sound level of 200 dB (ref. 1 μPa @ 1m) in water at the driving input power of 650 VA and 130 mmϕ

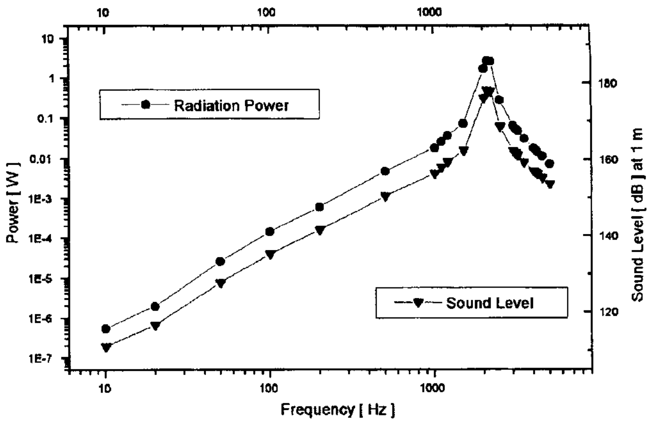


Fig. 7. Radiation power and sound level depend on the driving frequency of the transducer at constant ac voltage mode.

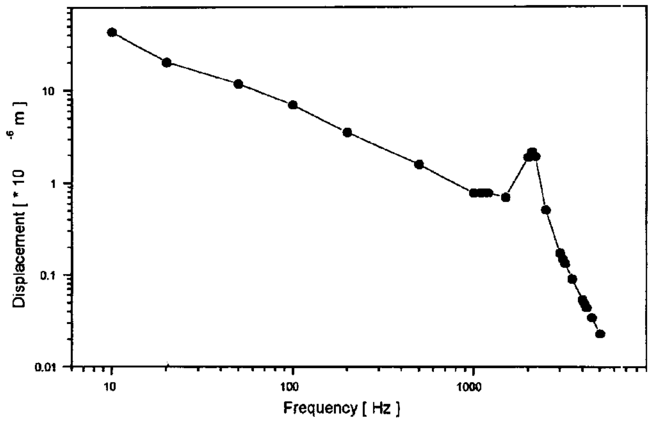


Fig. 8. Displacement of sonar transducer depends on the driving frequency of the transducer at constant ac voltage mode

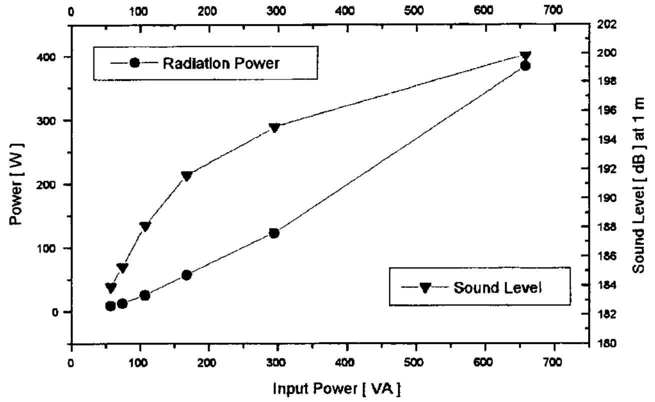


Fig. 9. Radiation power and sound level depend on the driving input power of the transducer at resonance frequency.

diameter of radiation disk.

5. Conclusion

For the improvement of heat dissipation problem of sonar transducer using Terfenol-D, we have constructed an open magnetic circuit type under water sonar transducer using Terfenol-D rod of 100 mm in length and 6 mmϕ in diameter. The resonance frequency of the constructed transducer was 2.1 kHz and we can achieved sound radiation power of 200 dB at input power of 650 VA at the resonance frequency.

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