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Sound detection characteristics under different positions of the fiber optic sensor arrays using Sagnac interferometer

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ABSTRACT

In this paper, directional sensitivities of the fiber optic acoustic sensor arrays are showed experimentally. Three diffrent directions were selected as vertical, horizontal, and longitudinals. Fiber optic sensor was made by using aluminum mandrel which is hollow cylinder and about 50m optical fibers were wounded on the mandrel. Non-directional sound speaker was used as a sound source. Sagnac interferometer was used to measure the sound source. Two fiber optic sensors are used to make arrays. Measurement sound signal was showed in the frequency domain and these results were compared to the microphone's detected signal. Based on the experimetal results sensitivity of the fiber optic acoustic sensor is depended upon the mandrel directions.

INTRODUCTION

Fiber optic sensors are widely used in the industrial and military fields[1]. To detect external sound signals on the mandrel structure, Sagnac interferometer can be fabricated and tested. Because of easy construction Sagnac interferometer was selected rather than Fabry-Perot type. Generally hollow cylinder mandrel has been widely used to make fiber optic sensor[2-3]. The Sagnac fiber optic interferometer is as shown in Fig. 1. In Fig. 1 it has two fiber optic sensors.

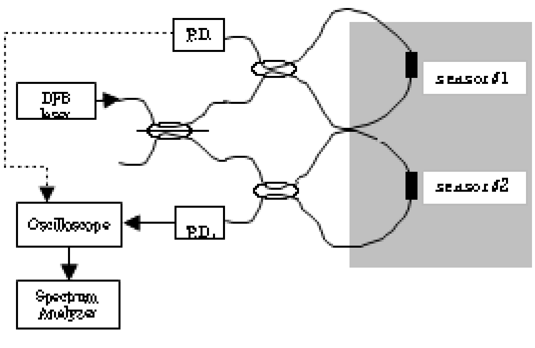

Figure 1. Sagnac interferometer with array

Fiber optic interferometric sensor has many significant advantages and in many applications several of the advantages can apply. Some of the advantages are increased sensitivity, EMI immunity, large bandwidth, and geometrical versatility. Fiber optic sensor for the acoustic applications has been researched in NRL, Litton, Ferranti Thomson, DRA, Plessey, Okki, TMS, and Whitehead. Types of the fiber optic interferometric sensor are Mach-Zehnder, Sagnac, Michelson, and Fabry-Perot. The four interferometers could be used to different purposes, respectively. Usually, for the detection of the sound and vibration, Mach-Zehnder and Sagnac interferometers are used because of easy configuration and high sensitivity.

The principle is input light split into two parts at the 2×2 coupler (beam splitter) and the two lights rotate opposite direction each other, then come together in 2×2 coupler. P.D.(Photo diode) detected the output signal with information of physical variation which experienced in the loop. Phase differences between the two lights is directly proportional to the acoustic and vibration pressure in the loop. Detected signal intensity is also proportional to the phase difference[4-6].

As shown in Fig. 1, the radius of closed loop is R, angular velocity is Ω, tangential velocity is v, wave length is λ, speed of the light is c. The two lights rotate the loop, phase difference is expressed as

$$\Delta\phi = m\frac{8\pi A}{c\lambda}\Omega = \frac{4\pi LR}{c\lambda}\Omega \qquad (1)$$

In eq. (1), the sensitivity or phase difference of the fiber optic sensor in Sagnac interferometer is proportional to the closed loop length L. Generally, fiber optic interferometric sensor used mandrel type as a sensor. fiber wounded around a hollow cylinder. Acoustic pressure applied to the surface of the sensor. However, the mandrel type sensor do not appropriate for the use of distributed system such as latticed fence system.

EXPERIMENTAL SETUP

Mandrel sensor fabricated with dimension of 30mm in diameter and 2.5cm in height, the optical fiber, 50m in length, wounded on the mandrel. For the detection of the sound signals, single mode fiber, a laser with 1,550nm in wavelength, 2x2 coupler, PZT phase modulator were used. It was verified the sensitivity of the Sagnac interferometer using the PZT phase modulator. Fiber-optic external sound signal applied to the sensor surface from 500Hz to several kHz. The detected optical signals were compared and analyzed to the detected microphone signals against time and frequency domain. Fig. 2 shows nondirectional speaker as a sound source. At this figure two fiber optic sensors are installed and their directions are stand and hole.

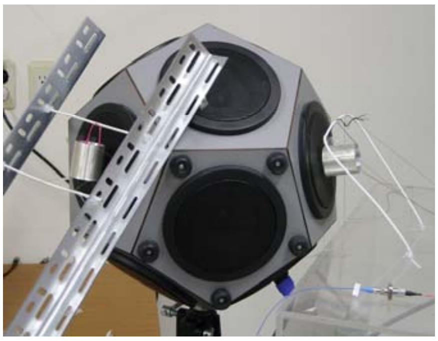

Figure 2. Nondirectional soun speaker and mandrel

Fig. 3 shows Sagnac interferometer and microphone on the tripod. At the optic table Sagnac interferometer can be installed with polarization controller.

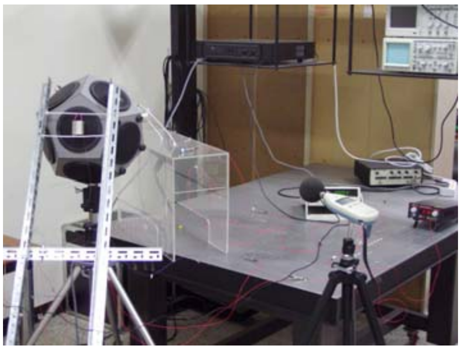

Figure 3. Photograph of the experimental setup

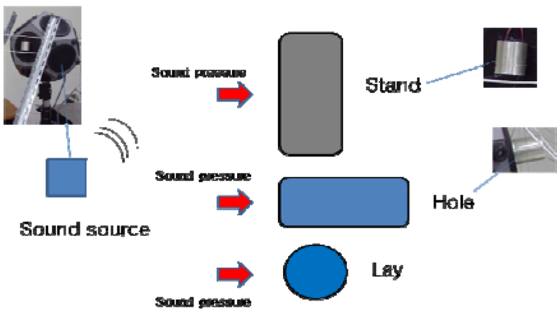

Figure 4. Direction of the fiber optic sensor which are stand, hole, and lay directions

Fig. 4 shows the installed fiber optic sensor's directions which are stand, hole, and lay directios. External sound pressure applied to the surface of the each direction and fiber sensor detected the signal. Microphone(RION NL-15) as shown in Fig. 3 can detect sound from the nondirectional speaker. In this experiments 0.5kHz, 1kHz, 2kHz, and 3kHz sound signals are used as input.

RESULTS AND DISCUSSIONS

In this experiments, "hole, lay, and stand" directions are used. Simply "hole" direction is that the sound travels in the hollow hole direction. Figure 5 and 6 show frequency spectrum of the detected signal at the fiber optic sensor in the direction of hole and lay, stand under frequency of 0.5kHz. In this case the detected signal's magnitude is lager on the order of stand>hole>lay as shown in table 1.

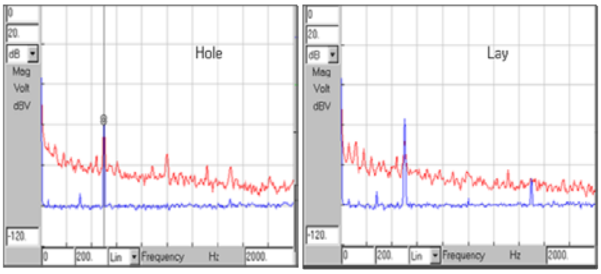

Figure 5. Frequency spectrum of the detected signal at the fiber optic sensor in the direction of hole and lay under frequency of 0.5kHz

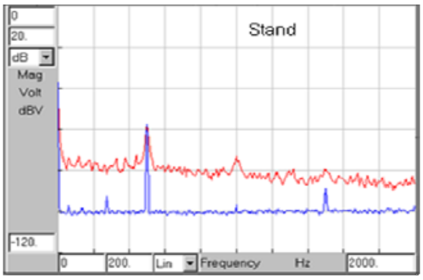

Figure 6. Frequency spectrum of the detected signal at the fiber optic sensor in the direction of stand under frequency of 0.5kHz

Table 1. Average detected signal magnitude of the fiber optic sensor(in the case of 0.5kHz input)

Freq.	direction	Avg.(dBV)
	stand	-55.965
0.5kHz	lay	-69.648
	hole	-58.296

Figure 7 and 8 show frequency spectrum of the detected signal at the fiber optic sensor in the direction of hole and lay, stand under frequency of 1.0kHz. In this case the detected signal's magnitude is lager on the order of lay>stand>hole as shown in table 2. Hole direction is the smallest.

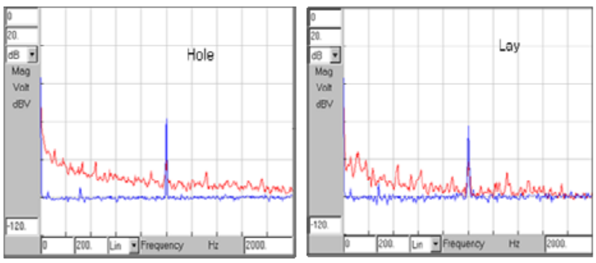

Figure 7. Frequency spectrum of the detected signal at the fiber optic sensor in the direction of hole and lay under frequency of 1.0kHz

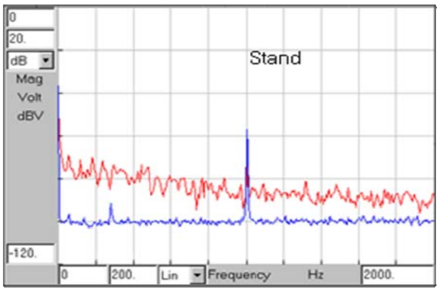

Figure 8. Frequency spectrum of the detected signal at the fiber optic sensor in the direction of stand under frequency of 1.0kHz

Table 2. . Average detected signal magnitude of the fiber optic sensor(in the case of 1kHz input)

Freq.	direction	Avg.(dBV)
	stand	-76.623
1kHz	lay	-76.450
	hole	-77.680

Figure 9 and 10 show frequency spectrum of the detected signal at the fiber optic sensor in the direction of hole and lay, stand under frequency of 2.0kHz. In this case the detected signal’s magnitude is lager on the order of lay>hole>stand as shown in Table 3. “Lay” direction is the largest.

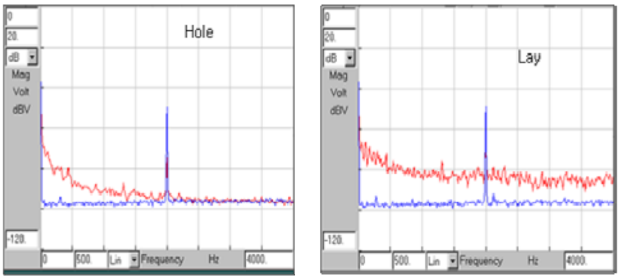

Figure 9. Frequency spectrum of the detected signal at the fiber optic sensor in the direction of hole and lay under frequency of 2.0kHz

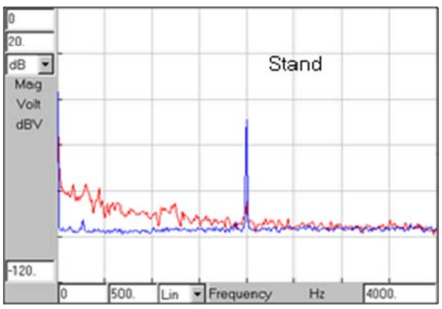

Figure 10. Frequency spectrum of the detected signal at the fiber optic sensor in the direction of stand under frequency of 2.0kHz

Table 3. . Average detected signal magnitude of the fiber optic sensor(in the case of 2kHz input)

Freq.	direction	Avg.(dBV)
	stand	-81.844
2kHz	lay	-67.063
	hole	-74.759

Figure 11 and 12 show frequency spectrum of the detected signal at the fiber optic sensor in the direction of hole and lay, stand under frequency of 3.0kHz. In this case the detected signal’s magnitude is lager on the order of lay>hole>stand as shown in table 3. “Lay” direction is the largest.

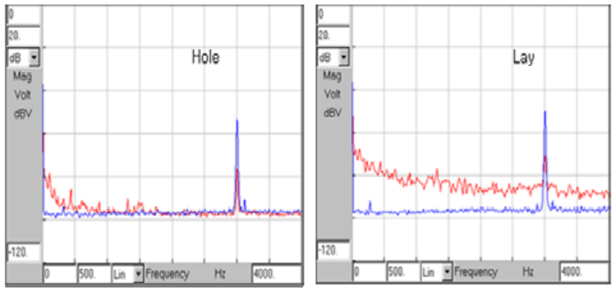

Figure 11. Frequency spectrum of the detected signal at the fiber optic sensor in the direction of hole and lay under frequency of 3.0kHz

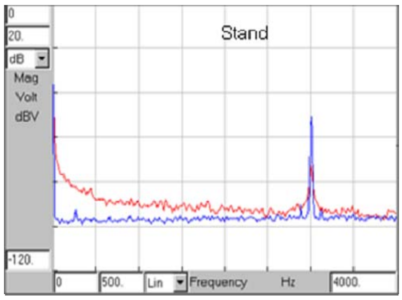

Figure 12. Frequency spectrum of the detected signal at the fiber optic sensor in the direction of stand under frequency of 3.0kHz

Table 4. . Average detected signal magnitude of the fiber optic sensor(in the case of 3kHz input)

Freq.	direction	Avg.(dBV)
	stand	-75.537
3kHz	lay	-66.833
	hole	-75.533

CONCLUSIONS

In this paper, directional sensitivities of the fiber optic acoustic sensor arrays are showed experimentally. Three diffrent directions were selected as vertical, horizontal, and longitudinals. Fiber optic sensor was made by using aluminum mandrel which is hollow cylinder and about 50m optical fibers were wounded on the mandrel. Non-directional sound speaker was used as a sound source. Sagnac interferometer was used to measure the sound source. Two fiber optic sensors are used to make arrays. Measurement sound signal was showed in the frequency domain and these results were compared to the microphone's detected signal. Based on the experimetal results sensitivity of the fiber optic acoustic sensor is depended upon the mandrel directions. This system can be expanded to fiber optic latticed fence structure for the monitoring of a significant

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