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Analysis of pressure distribution in cylindrical tube fluid flow using a fiber Bragg grating

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ABSTRACT

Fibre optic sensors have garnered considerable attention from scientists, leading to the extensive use of optical fibres as sensors for monitoring strain and temperature. The increasing adoption of fibre Bragg gratings (FBG) can be attributed to their enhanced sensitivity and rapid transmission speed. The objective of this study is to examine the pressure distribution of FBGs within a cylindrical tube while subjected to vibrations from a loudspeaker and the presence of hot water vapour. The given options were of two scenarios, first scenario had a tube without water vapour and a heart sound, while the second scenario included a tube with water vapour and a heart sound. In this experiment, we strategically placed the FBG at 20 different points along the cylindrical tube to accurately detect strain values at each position. The outcomes derived from these two scenarios illustrate that temperature and air vapour pressure exert an influence on the occurrence of sound, with the highest level of tension found when hot water vapour and heart sounds are present.

Keywords: Fiber Bragg grating; fluid flow; hot water vapor; sound; strain

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INTRODUCTION

Fiber Bragg grating (FBG) is an optical fiber with a grating in one of its segments. This grating reflects light that passes through it with a certain wavelength and passes the rest [1,2]. FBG is also widely used to detect the heart. Because the FBG system receives the human heartbeat in the form of pressure which results in changes in strain in the FBG [3-5]. Not only to strain, FBG also has high sensitivity to temperature [6,7]. This is what makes FBG widely used as a strain and temperature sensor. FBG-based sensors utilize the effect of changes in strain values, changes in strain in the FBG can be a function of temperature so by utilizing the impact of changes in strain due to temperature, the sensitivity of the sensor can be increased [8-10]. Based on the FBG sensor vibration monitoring system, the FBG sensor vibration can be designed for the detection system. Changes in the Bragg wavelength due to strain dynamics in the FBG can be measured by detecting changes in the Bragg wavelength [11,12].

This research presents an analysis of the pressure distribution resulting from a fluid flow design using a cylindrical tube where the tube contains a FBG to detect strains that occur due to vibrations from heart sounds. The variations given are: first, in the condition in the tube without water vapor and there is a heart sound, third, in the condition in the tube there is water vapor and there is a heart sound.

LITERATURE REVIEW

Optical fiber is a transmission medium that is capable of transmitting information with large capacity and high reliability. Optical fiber consists of 4 parts with the core and cladding as the main structure with an explanation of each part as follows [13-15]:

1. Core is the deepest part of an optical fiber. Made from fine glass fiber which will help the movement of light. This section has a size of 2 – 5 µm.

2. Cladding has a size of 5 – 250 μm and is made of silicone. Cladding is an outer material that protects the core and reflects the light it receives (radiates).
3. Coating/Buffer is defined as a mechanical protector that can protect optical fibers from external disturbances, such as cable bending and air humidity.
4. Strength Member and Outer, namely a fiber optic protective jacket that will protect the cable from interference that can damage the core.

FBG is an optical fiber with a grating in one of its segments. This grating reflects light that passes through it with certain wavelengths and passes the rest. FBG is widely used as a strain and temperature sensor [16]. The basic principle of FBG is transmitting and reflecting light that passes through it. Polychromatic light comes from a source that is further guided in an optical fiber. When light passes through a Bragg grating, part of the light will be reflected at a certain wavelength value or what is usually called the Bragg wavelength, and part of it will be transmitted through the FBG [17].

The Bragg wavelength due to the strain around the FBG can be expressed in the following equation [18]:

$$\Delta\lambda_{B,1} = \lambda_B (1 - p_\alpha)\varepsilon \tag{1}$$

$$\Delta\lambda_B = \lambda_{B,1} - \lambda_{B,0} \tag{2}$$

where $\lambda_{B,0}$ is the reference wavelength before the FBG is placed on the cylindrical tube, $\lambda_{B,1}$ is the wavelength after the FBG is placed on the cylindrical tube, $\Delta\lambda_{B,1}$ is the wavelength shift (nm), λ_B is the Bragg wavelength (nm), $p_\alpha \approx 0.22$ is the photo-elastic coefficient of the optical fiber, ε is the strain (με or microstrain).

Based on the FBG sensor vibration monitoring system, the FBG sensor vibration can be designed for the detection system. From the FBG strain sensor model, it can be seen that if the FBG strain is a periodic dynamic strain that changes over time and changes due to the influence of object vibrations, then the model can be used to measure the vibration period. For vibration characteristics, the main parameters are acceleration, amplitude, speed, and vibration frequency [19,20]. In this way, the FBG vibration sensing system can be designed. Changes in the Bragg wavelength due to strain dynamics in the FBG can be measured by detecting changes in the Bragg wavelength [9].

Sound is a longitudinal wave that propagates in a medium (solid, liquid, or gas). These waves are a form of energy. Sound energy comes from vibrating objects, the propagating vibrations are called waves, therefore sound propagates in the form of waves [21]. A loudspeaker is an electroacoustical transducer that converts electrical signals into sound vibrations. The electrical signal produced by the amplifier is transmitted to the loudspeaker. Speakers carry electrical signals and convert them back into physical vibrations to produce sound waves. The loudspeaker converts the electrical signal into an analog sound signal [22].

RESEARCH METHODS

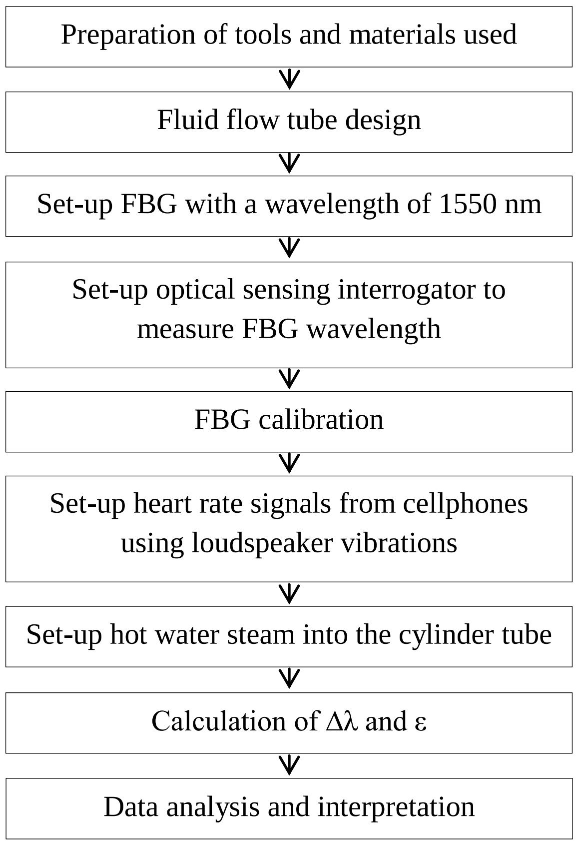

Figure 1. Research flow diagram.

The flow diagram of this research can be seen in Figure 1. This research method was carried out to analyze the pressure distribution due to sound vibrations in a cylindrical tube using a loudspeaker which was detected by the FBG and by changes in temperature in the tube due to hot water vapor being applied.

RESULTS AND DISCUSSION

In this chapter, the results of the FBG response to strains caused by loudspeaker sound vibrations and hot water vapor placed in a cylindrical tube-shaped medium are discussed. This research was divided into 2 conditions, namely the condition without water vapor and heart sounds (condition 1), and the condition given water vapor and heart sounds (condition 2).

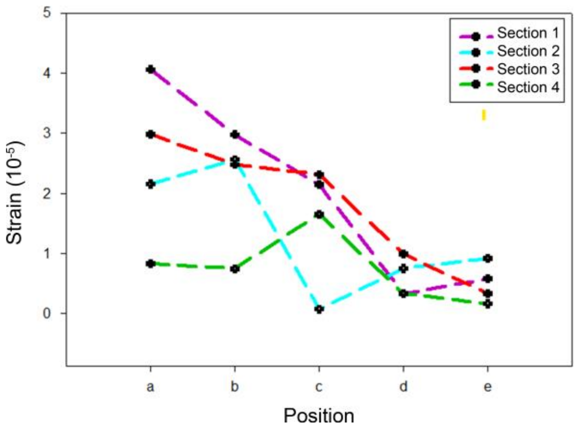

Figure 2. Graph of FBG position versus strain value under conditions without water vapor and heart sounds.

Figure 2 shows that the highest strain value is located at position 1a with a strain value of 4.059×10^{-5} ε with a flow velocity in the tube of 0.099 m/s and the lowest strain value is located at position 2c with a strain value of 7.586×10^{-7} ε with The flow velocity in the tube is 0.083 m/s. Based on the graph, it can also be seen that section 1 experienced a decrease in strain values from positions a to e with values ranging from 4.059×10^{-5} ε to 5.789×10^{-6} ε with a flow velocity range in the tube of 0.060 – 0.129 m/s.

Figure 3 shows the distribution of air in the tube when the tube is without steam while sound is given, meaning that from the bottom side, no hot steam pressure is given, but it can be seen that almost half of the change in strain value occurs at the air pressure at the top, this can be caused by from the inhomogeneous distribution of sound produced by the heartbeat so that the upper part has a relatively higher strain value than the lower part. Furthermore, measuring the pressure distribution conditions in conditions without water vapor and given that the heart sounds should appear homogeneous, but due to the high sensitivity of the strain value of the FBG measuring instrument, the FBG records extreme positions at the top with a range of 3×10^{-5} ε up to 4×10^{-5} ε and the extreme position at the bottom where the bottom of the range is 1×10^{-5} ε to 2×10^{-5} ε. It can be said that sound influences the pressure or strain also at the bottom, but lower than at the top. Another thing that causes the top is that the air experiences upward pressure, resulting in stretching strains at the top.

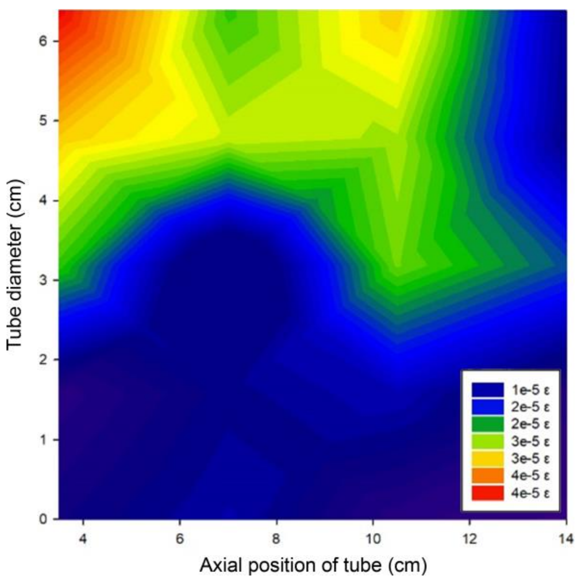

Figure 3. Distribution of strain values for conditions without water vapor and heart sounds.

Figure 4 shows that the highest strain value is located at position 2d with a strain value of 1.083×10^{-4} ε with a flow velocity in the tube of 0.076 m/s and position 2e with a strain value of 1.232×10^{-4} ε with a flow velocity in the tube of 0.129 m/s, the high strain value is due to the position of the FBG being close to the source of hot water vapor which is around section 2. From the graph, it can also be seen that on average at position b the strain value has decreased from other positions, namely with a range of 8.271 × 10^{-7} ε to 1.819 × 10^{-5} ε with a flow velocity range in the tube in position b of 0.088 – 0.109 m/s.

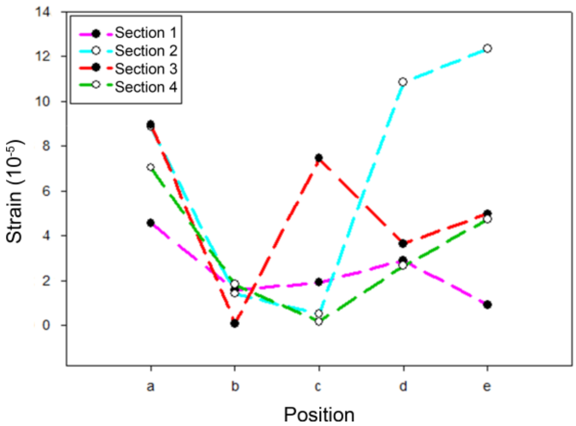

Figure 4. Graph of FBG position versus strain value in conditions of water vapor and heart sounds.

There is steam entering from below the axial axis, while on the left there is sound entering, there is an accumulation of functions between sound and steam flowing from below (see Figure 5). So, there is a resultant relationship between sound and steam. Sound is more about pressure, while steam is more about pressure, the thermal density of the air in the tube, the image shown shows an increase in extreme changes, a shift in the strain value at the sound source, and the flow reaches the middle position of the tube because the sound source is not homogeneous, but because of pressure. This sound causes the hot air to shift towards the right. Meanwhile, at the top of the tube, there is a blocked flow, namely a high strain value due to the airflow that has been blocked at the top so that it does not flow out. In the middle of the tube, sound can flow in an open cylindrical tube, this is because firstly, the effect of steam is influenced by sound, and secondly, the effect produced by water vapor is small compared to heart sounds which exert pressure on air movement, meaning the density of the surrounding air. The middle tube is controlled by sound, as evidenced by the fact that the steam does not contribute much to all points except being retained at the top and some at the bottom, where the bottom is close to the heat source and at the top is retained due to the effects of convection and conduction.

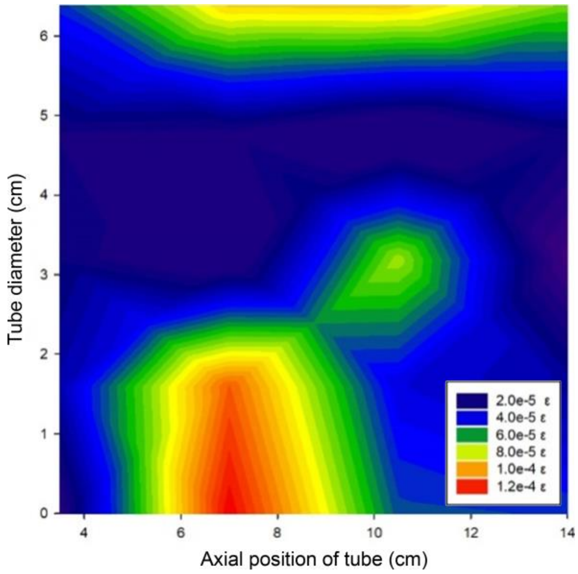

Figure 5. Distribution of strain values for conditions of water vapor and heart sounds.

CONCLUSION

A fluid flow design has been carried out to determine the strain in the Bragg lattice fibers in a cylindrical tube using FBG. The design of the tube is in the form of an FBG laying medium as a sensor to detect changes in pressure in the tube in the form of changes in strain values that occur due to the influence of sound and the influence of applied water vapor. Conditions without water vapor and heart sounds show that almost half of the change in strain value occurs in the air pressure at the top. This can be caused by the inhomogeneous distribution of sounds produced by the heartbeat so that the top part has a relatively higher strain value than the lower part. When water vapor is applied and heart sounds are given, it is shown that there is an increase in extreme changes in the shift value of the strain at the sound source and the flow reaches the middle area of the tube because the sound source is not homogeneous, but because of the sound pressure, the hot air shifts to the right.

REFERENCES

1. Shekar, P. R., Latha, D. M., Kumari, K. & Pisipati, V. G. K. M. (2021). Optimal parameters for fiber Bragg gratings for sensing applications: A spectral study. *SN Applied Sciences*, **3**(6), 666.
2. Veriyanti, V. & Saktioto, S. (2020). Tampilan birefringence pada gangguan pembengkokan serat optik komersial. *Indonesian Physics Communication*, **17**(2), 97–103.
3. Hongyao, W. (2011). Coal mine disaster rescue life sign monitoring technology based on FBG and acceleration sensor. *Procedia Engineering*, **26**, 2294–2300.
4. Fadilla, F. D. & Saktioto, S. (2021). Aplikasi sistem sensor fiber Bragg grating untuk pendeteksian simulasi denyut jantung. *Indonesian Physics Communication*, **18**(2), 151–158.
5. Saktioto, S., Maulana, A. M., Yupapin, P. & Hairi, H. M. (2023). Analysis of fluid flow in a cylindrical tube using fiber Bragg grating. *Science, Technology and Communication Journal*, **4**(1), 15–20.
6. Mishra, V., Lohar, M. & Amphawan, A. (2016). Improvement in temperature sensitivity of FBG by coating of different materials. *Optik*, **127**(2), 825–828.
7. Vaeruza, I., Kurniansyah, K. E., Darma, F. & Yulianti, I. (2019). Fabrikasi sensor serat optik plastik untuk deteksi ion logam merkuri dalam air. *Indonesian Physics Communication*, **16**(2), 123–129.
8. Zhang, Z. & Liu, C. (2017). Design of vibration sensor based on fiber Bragg grating. *Photonic Sensors*, **7**(4), 345–349.
9. Ramadhan, K. & Saktioto, S. (2021). Integrasi chirping dan apodisasi bahan TOPAS untuk peningkatan kinerja sensor serat kisi Bragg. *Indonesian Physics Communication*, **18**(2), 111–123.
10. Meyzia, B., Saktioto, S., Emrinaldi, T., Wanara, N., Hanto, D., Widiyatmoko, B. *et al*. (2024). Novel approach peak tracking method for FBG: Gaussian polynomial technique. *Science, Technology and Communication Journal*, **4**(3).
11. Kouhrangiha, F., Kahrizi, M., & Khorasani, K. (2022). Structural health monitoring: modeling of simultaneous effects of strain, temperature, and vibration on the structure using a single apodized π-Phase shifted FBG sensor. *Results in Optics*, **9**, 100323.
12. Ikhsan, R., Syahputra, R. F. & Saktioto, S. (2018). Analisis kompensasi dispersi menggunakan penguat Raman pada jaringan WDM (wavelength division multiplexing) dalam komunikasi serat optik. *Indonesian Physics Communication*, **15**(2), 88–92.
13. Saktioto, S., Defrianto, D., Hikma, N., Soerbakti, Y., Irawan, D., Okfalisa, O. *et al*. (2022). External perspective of lung airflow model via diaphragm breathing sensor using fiber optic belt. *The 4th Al-Noor International Conference for Science and Technology*, **4**(1), 1014.
14. Sutriyono, D. P. & Saktioto, S. (2017). Karakteristik pertumbuhan pelepah kelapa sawit dengan menggunakan fiber Bragg grating moda tunggal. *Indonesian Physics Communication*, **14**(1), 1026–1031.
15. Saktioto, S., Nurpadilla, R., Meyzia, B., Hairi, H. M., Fadhali, M. M., & Yupapin, P. (2024). Characteristics of human voice vibrations based on FBG strains. *Science, Technology and Communication Journal*, **4**(2), 31–36.
16. Presti, D. L., Massaroni, C., Leitao, C. S. J., Domingues, M. D. F., Sypabekova, M., Barrera, D. *et al*. (2020). Fiber bragg gratings for medical applications and future challenges: A review. *IEEE Access*, **8**, 156863–156888.
17. Hillmer, H., Woidt, C., Kobylinskiy, A., Kraus, M., Istock, A., Iskhandar, M. S. *et al*. (2021). Miniaturized interferometric sensors with spectral tunability for optical fiber technology—A comparison of size requirements, performance, and new

concepts. *Photonics*, **8**(8), 332.
18. Li, R., Tan, Y., Chen, Y., Hong, L., & Zhou, Z. (2019). Investigation of sensitivity enhancing and temperature compensation for fiber Bragg grating (FBG)-based strain sensor. *Optical Fiber Technology*, **48**, 199–206.
19. Li, T., Guo, J., Tan, Y. & Zhou, Z. (2020). Recent advances and tendency in fiber Bragg grating-based vibration sensor: A review. *IEEE Sensors Journal*, **20**(20), 12074–12087.
20. Emrinaldi, T. & Saktioto. (2016). Penentuan nilai regangan Jembatan Siak I oleh kendaraan bermotor menggunakan fiber Bragg grating. *Indonesian Physics Communication*, **13**(13), 919–926.
21. Anggelia, S., Rahmawati, R., Setiawati, A. & Kurniawati, W. (2023). Diving into the World of Sound and Light, Understanding Their Properties, Propagation and Uses. *Jurnal Pendidikan Indonesia*, **2**(1), 119–125.
22. Klippel, W. (2020). Loudspeaker and headphone design approaches enabled by adaptive nonlinear control. *Journal of the Audio Engineering Society*, **68**(6), 454–464.