A STUDY OF THE OPTICAL BENDING SENSOR CHARACTERISTIC FOR DISTRIBUTION UNDERGROUND CABLE JOINT

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ABSTRACT

In this paper, we proposed an optical bending sensor using an LPG pair that can simultaneously check the degree of bending and bending direction of underground power lines and joints. The 2ch TOSA used as a light source in the proposed sensor system was fabricated using 1570nm and 1590nm CWDM-DBF LD module. The 2ch ROSA for wavelength detection was fabricated using two InGaAs PIN PDs and wave block filters. From the experimental results, it was showed a 10 dB dip change at 1mm bend depth and a peak change at 8 dB at 1.12g / cm^2 *pressure.*

INTRODUCTION

The underground power cable is mainly installed in a dense urban area and is managed by one of the important distribution facilities. Since the water is occasionally flowed into the underground manhole due to the inflow of sewage or nature/storm water, it is not easy to monitor the health index of underground power cables and facilities with conventional sensors [1,2]. In addition, there is a possibility of cable breakdown due to the ground subsidence around manhole caused by inflow of rain or sewages. Even in a flooded environment inside a manhole, health-index monitoring of underground power cables can be easily performed by fiber-optic sensors.

There are significant advantages to using fiber optic sensors, such as small size, light weight, and low-cost remote high-speed measurement functions, as well as dielectric properties of fiber [3-6]. In addition, high voltage and magnetic measurement capabilities, wavelength multiplexing capabilities and isolation at high line potentials provide linear response over a wide range of measurements. Previous studies have been conducted to measure tensile force, temperature, bending, and vibration using a fiber grating sensor [7, 8].

This paper proposes a simple fiber-optic sensor structure using long period grating (LPG) pair interferometers that can simultaneously identify the direction and quantity of bending of underground power cables and joints. The advantage of the proposed sensor is that it can be manufactured as a robust system insensitive to disturbance compared to previous long period grating (LPG) sensors and is very sensitive to small bending depth and pressure. In addition, permanent monitoring system can be applied as a measurement system at any time, and the bending and pressure direction of the structure can be determined at the same time.

FIBER OPTIC BENDING SENSOR

The fiber Bragg grating, which changes the refractive index at regular intervals in the optical fiber core, has high sensitivity to the reflection and the transmission spectrum of sensors according to changes in external mechanical and thermal physical quantities. The short period grating causes the coupling between the core modes, while the long period grating is the medium that couples the light traveling in the core mode into the cladding mode in the same direction. The coupled cladding mode is generally scattered or absorbed in the coating layer outside the cladding and does not return to the core mode and forms a loss band in the transmission spectrum of the device.

The resonance condition of the LPG according to the changing physical quantity is as follows.

$$\lambda_{\max,\,\min} = \frac{\Lambda(n_{eff}^{core} - n_{eff}^{clad})}{1 + (\kappa_{clad} - \kappa_{core})\Lambda / 2\pi} \qquad (1)$$

The equation (1) is the coupling coefficient of the core mode and the cladding mode. The center wavelength of the loss band of the LPG due to the external physical change is affected by the coupling coefficient. As a result, the center wavelength of the loss band is determined by the difference in coupling coefficient.

When the tensile strain is applied to the LPG, the coupling coefficient of the grating increases, and the loss of the central wavelength of the loss band becomes larger. The coupling coefficient decreases when stress is applied to the inside of the LPG. Therefore, the center wavelength of the loss band of the LPG becomes small [9].

Generally, a cladding mode coupled by a long period grating fails without returning to core mode, but if it meets the same grating, it returns to core mode and causes interference.

As shown in Figure 1, the input light source on the first grating is divided into core and cladding modes, and two lights interfere with each other through the second grating. At this time, the interference pattern is given by the intensity of each mode and the transmitted length.

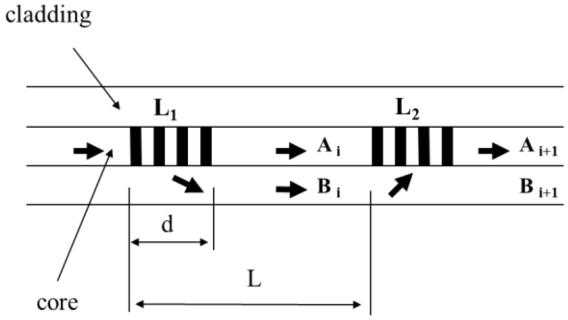

Figure 1. Structure of long period grating pair

The equation (2) for the transmission waveform of a long-period grating pair is from the coupled-mode theory, after the grating having the length d length passes through the core and the cladding mode.

$$A = e^{i\frac{\beta_{co}+\beta^{v}_{cl}}{2}d}\begin{bmatrix} e^{i\frac{K}{2}d} & 0 \\ 0 & e^{-i\frac{K}{2}d} \end{bmatrix}\begin{bmatrix} \cos sd + \dfrac{i\Delta\beta \sin sd}{2s} & \dfrac{ix \sin sd}{s} \\ \dfrac{ix^{*} \sin sd}{s} & \cos sd - \dfrac{i\Delta\beta \sin sd}{2s} \end{bmatrix} \quad (2)$$

Where β_{co} and β^{v}_{cl} are the propagation constants of the core and cladding modes, respectively, K is the grating vector, $K = 2\pi / \Lambda$ (Λ is the grating period) and $\Delta\beta$ is the phase mismatch ($\Delta\beta = \beta_{co} - \beta^{v}_{cl} - K$). Using the matrix for the spacing L between gratings, the mode size of the long period grating pair can be expressed as:

$$\begin{bmatrix} a_{co}(2d+L) \\ a^{v}_{cl}(2d+L) \end{bmatrix} = A\begin{bmatrix} e^{i\beta_{co}L} & 0 \\ 0 & e^{i\beta^{v}_{cl}L} \end{bmatrix} A \begin{bmatrix} a_{co}(0) \\ a^{v}_{cl}(0) \end{bmatrix} \quad (3)$$

The fringe spacing (S) of the interference fringes caused by long period grating pairs is proportional to the square of the operating wavelength (λ) and inversely proportional to the spacing (L) between gratings as shown in the following equation (4).

$$S = \lambda^{2} / \Delta n_{g} L \quad (4)$$

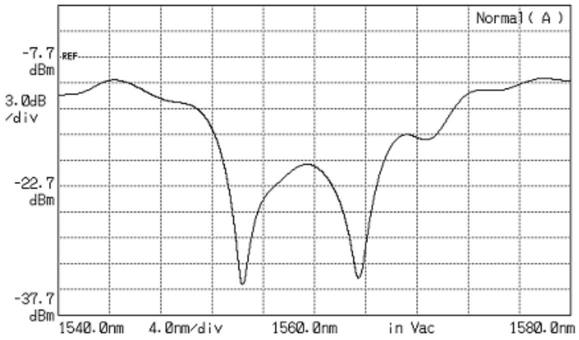

Figure 2. Transmission wavelength spectrum of LPGs pairs

Figure 2 shows the transmission spectrum of a LPGs pair. A fiber optic bending sensor was fabricated using two LPGs with a center wavelength of 1565 nm. As shown in the figures below, two fiber optic banding sensors were fabricated using a pair of LPGs with center wavelengths of 1565 and 1603 nm.

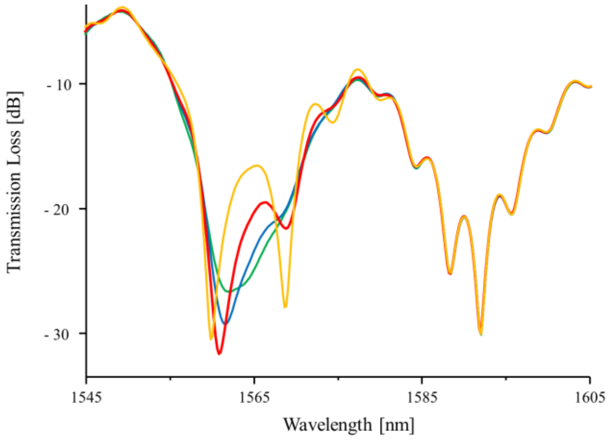

Figure 3. The wavelength spectrum with bending applied to the first LPGs pair

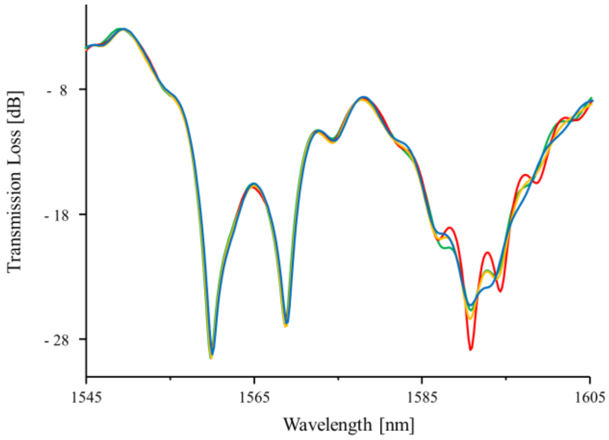

Figure 4. The wavelength spectrum with bending applied to the second LPGs pair

EXPERIMEMTAL RESULTS

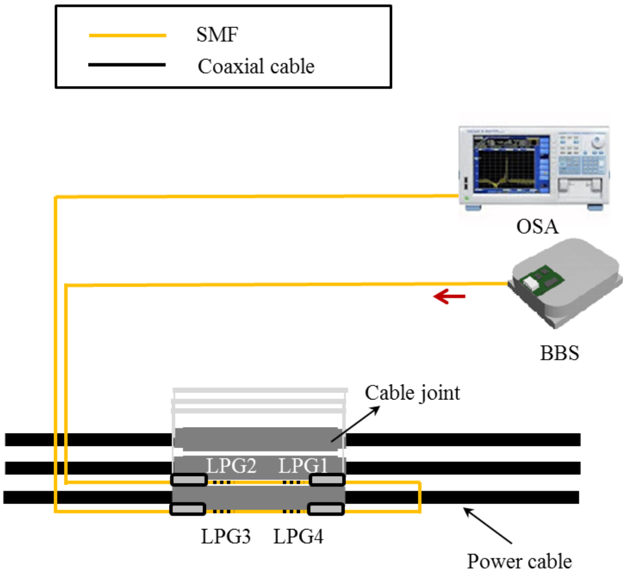

Figure 5. Experimental setup with an OSA and BBS

Fiber-optic bending sensor consisted of two LPGs and fiber connector, and two fiber-optic bending sensors were configured to attach to the upper and lower parts of the power cables and joints to measure the directions and quantities of bending. The bending quantity and direction are confirmed through optical spectrum analyzer (OSA) by examining the transmission spectrums of LPGs interferometer according to bending. As a light source, a broadband source (BBS) having a wavelength range of 1520 to 1620 nm was used.

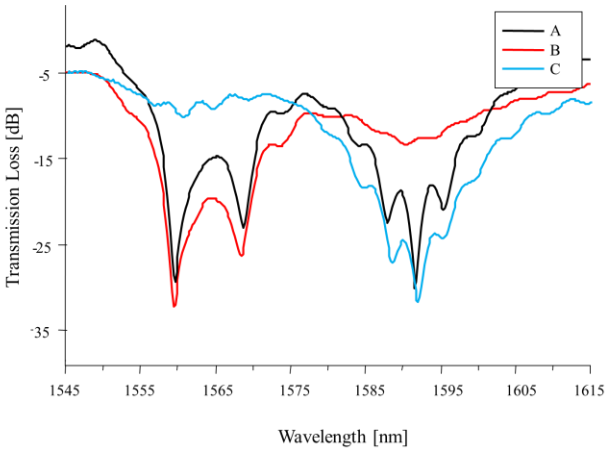

Figure 6. Wavelength spectrum of two LPGs pairs according to bending direction

Figure 6 compares the transmission spectrum of two LPGs pairs according to the direction of bending. Line A is the spectrum of the initial state of the fiber optic bending sensor pairs. Line B is the spectrum with the bending applied at the bottom of the power cable joint and line C is the spectrum with bending applied above the joint. By observing the changes in the wavelength spectrum, we could easily determine the direction of the power cable joint and the cable bend.

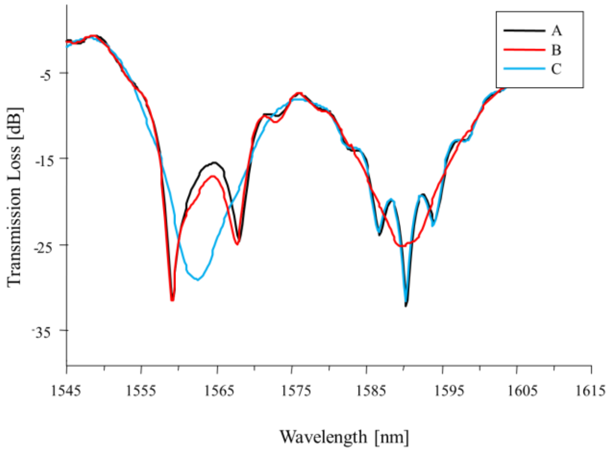

Figure 7. Wavelength spectrum of two LPGs pairs according to pressure direction

Figure 7 compares the transmission spectrum of two LPGs pairs according to the applied pressure direction.

Line A is the transmission spectrum of the initial state of the fiber optic sensor with two LPGs pairs, line C is the pressure of 0.0112 kg / cm^2 applied to the optical fiber portion between the first pair of gratings, line B is the optical fiber portion between the second pair of gratings is 0.0112 kg / cm^2.

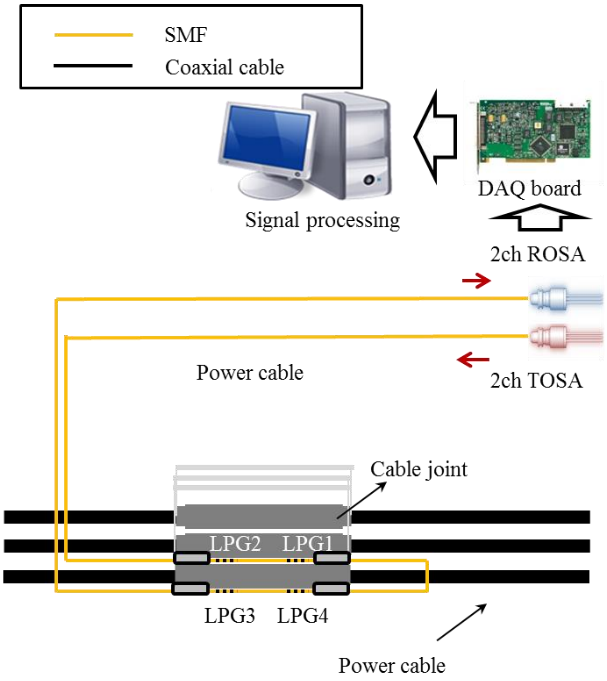

Figure 8. Experimental setup with an 2ch ROSA and TOSA

The proposed fiber-optics bending sensing system, which consists of LPG interferometers, transmitter optical sub-assembly (TOSA) and receiver optical sub-assembly (ROSA), is easily distinguished the direction of bending or pressure applied to the cable. The 2ch TOSA used as a light source in the proposed sensor system was fabricated using 1570 nm and 1590 nm CWDM-DBF LD module. The analog bandwidth and optical output of the CWDM DFB LD used in the proposed sensor system were 25 GHz (@30 mA) and 3 dBm, respectively. The 2ch ROSA for wavelength detection was fabricated using two InGaAs PIN PDs and wave block filters. The output values obtained from the PD were processed using a DAQ (Data Acquisition) board and a computer via a noninverting amplifier. The final output was calculated using the Lab View program.

In order to quantify the change of the transmission spectrum due to bending, we measured the depth change of the dip of the center wavelength of the loss band of the long period lattice pair while changing the bending depth applied to the power cable. It can be seen that the bending depth of about 10 ㎜ in the figure shows a large change of about 10 dB and it is possible to construct a very sensitive bending sensor from this.

We had an obtainment of 10 dB of dip change for 1 mm bending depth

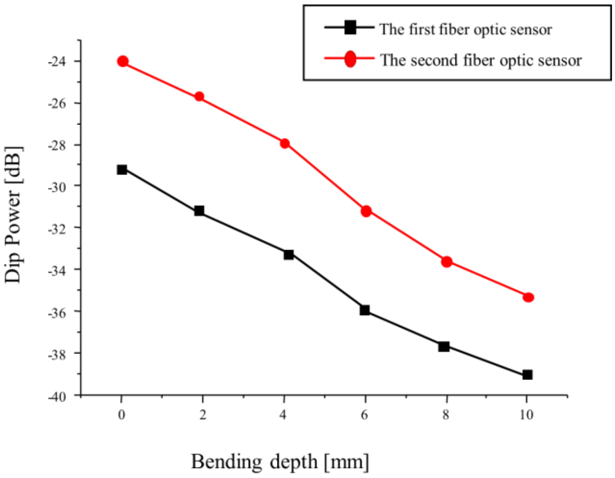

Figure 9. Variation of output of fiber optic sensor according to applied bending quantities.

In order to quantify the change of the transmission spectrum due to the pressure of the optical fiber between the long period grating pairs, the change in the depth of the peak of the interference wavelength of the loss band of the long period grating pair was measured while varying the pressure applied to the optical fiber between the grating pair. It can be seen from the figure that the pressure change of 0.0112 kg / ㎠ brings about 8dB variation, which makes it possible to construct a very sensitive pressure sensor.

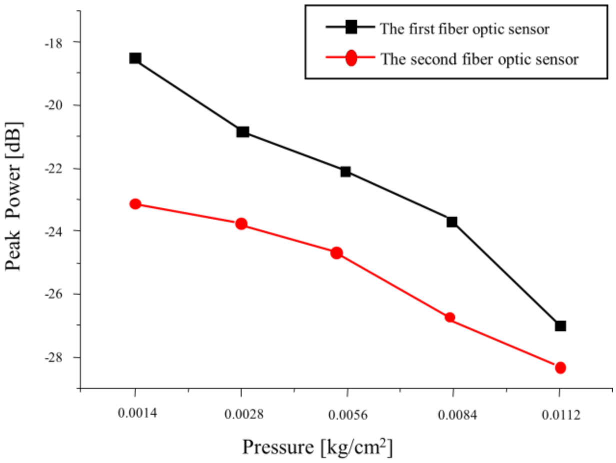

Figure 10. Variation of output of fiber optic sensor according to applied pressure.

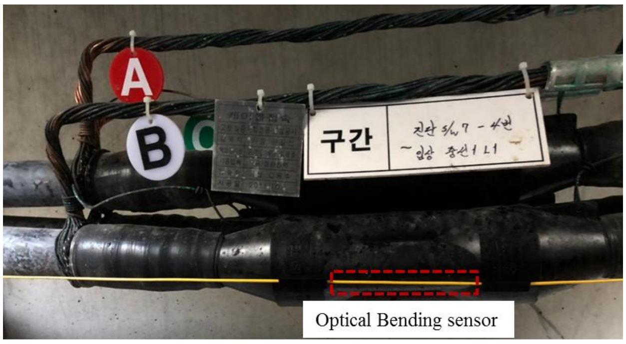

Figure 11. Proposed fiber optic sensor on the underground cable joint.

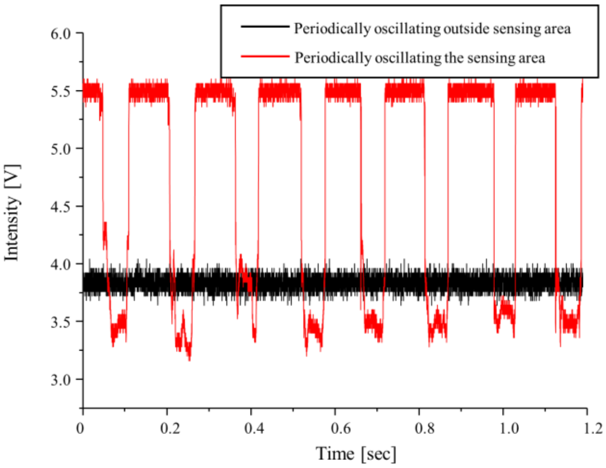

Figure 12. Experimental results of vibration test on fiber optic sensors

The change of the PD output was measured by the change of the loss band when periodic vibration was applied to the optical fiber part between the long period grating pairs and the change of the PD output when vibration was applied to the remaining optical fiber except for the sensor part was measured. It can be seen from the figure that the remaining optical fibers except for the sensor part are insensitive to vibration, and it is possible to construct a sensor that is insensitive to external disturbance.

CONCLUSION

The proposed sensor using a LPG pairs can simultaneously check the bending and bending directions of underground distribution power cable and joints. The efficiency of the proposed sensing system will be verified by applying it to underground distributed power lines. From the experimental results, we confirmed that our system is possible to obtain 10dB of dip change for 1mm bending depth. In addition, experimental results show that the proposed sensor system can measure not only bending but also pressure and vibration of underground power cables. The efficiency of the proposed sensing system will be verified by applying it to underground distributed power lines.

Acknowledgments

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