CABLE TEMPERATURE MEASUREMENT SYSTEM USING FIBER BRAGG GRATINGS

Abstract. This article discusses a cable temperature measurement system using fiber Bragg gratings. The overhead power line cable temperature measurement and extension system tilted a power line wire, which consists of two fittings, in which there are grooves in the fittings, in which a copper plate with a certain length is stuck, in the copper plate there is a hole in which epoxy resin is poured, an tilted fiber Bragg grating, which is recorded on a multi-mode optical fiber, an optical coupler, an ultraviolet excimer laser and a fiber optic connector, a light power detector. Experimental results show. That the measurement error and the error of the sensor calibration result is 0.0634°C; the time of finding a system malfunction does not exceed 3.24 s. The system has high measurement accuracy and excellent stability, can be adapted to real temperature measurement systems, and has a certain practical value.

Keywords: fiber optic sensor, Brag gratings, temperature, cable.

Introduction.
At present, due to the rapid formation of society and the constant progress of science and technology, the branch division is continuously strengthened, and the external conditions necessary for working in any industry become more and more stringent. Only if the necessary criteria are met, it is possible to guarantee the good operation of any part of the system and the equipment can work in a coordinated manner. These conditions are especially embraced by the fact that the branches of various branches of industry are continuously divided and can normally function. A whole range of equipment covers many modules. To provide the typical operation of the equipment, any section of the system is required to do in a stable area to meet practical needs. As equipment continues to evolve in the direction of miniaturization and intellectualization, the sensors are suitably quite small and can form a network to measure the entire system.

Temperature is a physical quantity that characterizes how hot or cold an object is. The main parameter that must be strictly defined for the control of special equipment is temperature. On the one hand, temperature is a key parameter that must be constantly determined and controlled in electrical equipment and scientific experiments; on the other hand, since changes in temperature may require changes in voltage, concentration and pressure, temperature monitoring in the real-time system is carried out using electrical equipment.

Fiber Bragg gratings have been extensively applied to electrical equipment prediction, structural health monitoring, power system fault monitoring and other real-world indication cases due to the rare superiority of EMI immunity, low melting loss, high sensitivity, small size, and easy distributed measurement. Fiber grating has been extensively applied in realistic

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detection applications such as electrical equipment monitoring, system status monitoring, and power system fault monitoring. The study of the grid temperature measurement system for smart electrical equipment is of great importance. This article mainly discusses the temperature measurement design of the optical fiber array of smart electrical equipment.

Rapid and active progress in different areas of the industry is intensifying the development of sensor systems, especially in terms of their performance, speed and accuracy. The still emerging industry calls for detailed and broad information about physical parameters such as deformation, gas concentration, temperature and others to realize independent control and improve remote diagnostics [1,2,3,4]. In [5,6] they created and researched clear information about the temperature in electrical power transformers, which can lead to early detection of a fault or overload, which is possible to support the planning of industrial maintenance intervals. Moreover, temperature and strain measurements can help detect battery expansion or be used to optimize the structure of power designs, which is positive for the formation of electro mobility [7,8,9,10]. In most applications operating in harsh and complex environments, scientists and companies around the world consider fiber Bragg gratings to be an excellent choice for multi-parameter sensing [11,12].

The development of fiber optic sensors has been promoted for decades [13,14,15]. Because the Bragg grating sensor is embedded in an optical fiber and operates in light, it is naturally immune to harsh environmental conditions. That is why these sensors have found many applications in a wide range of industries. For example, FBG has been found to be excellent for both temperature and strain measurement [13], energy infrastructure prediction [16], military use, or even space mission parts prediction [17,18]. High temperature sensing, especially in harsh environments where fiber-based sensing appears to be one of the few viable options. Indeed, most of the studies reported use FBGs to measure temperatures down to hundreds of degrees Celsius. Although there are still separate areas of application that call for immeasurably more spacious temperature ranges and therefore the optimization of all measuring systems [19,20]. On the effect of photosensitivity in doped fibers, many varieties of FBG structures have arisen, especially femtosecond gratings [21,22] and functionalized gratings, which can be obtained through sputtering of optical fiber with various chemical syntheses or polymers [23,24,25].

The current formation of FBG technology is mainly focused on sensor applications [26], and an impressive need is emerging towards the field of bulk sensor systems based on optical designs [27,28,29].

Materials and methods.

The Bragg wavelength $\lambda_B$ of a fiber Bragg grating with a spatial period $\Lambda$ and an effective refractive index $n_{eff}$ is determined by the formula [1]

$$\lambda_B = 2n_{eff}\Lambda.$$  

Thus, the change in $\lambda_B$ corresponding to small changes in the measured value $X$ will be equal to

$$\delta\lambda_B = \frac{d\lambda_B}{dX} \delta X = 2\left(\Lambda \frac{dn_{eff}}{dx} + n_{eff} \frac{d\Lambda}{dx}\right) \delta X = \lambda_B \left(\frac{1}{n_{eff}} \frac{dn_{eff}}{dx} + \frac{1}{\Lambda} \frac{d\Lambda}{dx}\right) \delta X = \lambda_B \left(\alpha_{n_{eff}} + \alpha_{n_{eff}} \frac{d\Lambda}{dx}\right) \delta X,$$  

where $\alpha_{n_{eff}}$ and $\alpha_{\Lambda}$ are, respectively, the specific expansion coefficient and the coefficient of change in the refractive index of the fibrous material caused by X. In the absence of changes in parameters other than temperature, the change in the Bragg wavelength is thus determined
\[ \delta \lambda_B = \lambda_B (\alpha_{n,x} + \alpha_{n,\lambda}) \delta T = \lambda_B (\zeta + \alpha_L) \delta T = \lambda_B \zeta \delta T, \]  

(3)

where \( \zeta \) and \( \alpha_L \) - term optical coefficient FBG and coefficient of thermal expansion, the sum of which gives the thermal coefficient of the Bragg wavelength \( \xi \). When using an FBG, it is often convenient to express \( \delta \lambda_B \) in terms of its temperature sensitivity over the wavelength \( \Psi_T \) such that:

\[ \delta \lambda_B = \Psi_T \delta T, \]  

(4)

where \( \Psi_T = \lambda_B \xi \), which for a fiber optic sensor \( \lambda_B = 1.5 \, \mu m \) has a typical value of \( \sim 10 \, \mu m/K \) at room temperature. In most measurements, the temperature is above the temperature of ice up to the upper temperature limit FBG of \( \sim 103 \, K \). The total change in the Bragg wavelength \( \Delta \lambda_B \):

\[ \Delta T = -\frac{1}{\Psi_T} d \lambda_B = \Psi_T^{-1} \Delta \lambda_B. \]  

(5)

As the temperature decreases, \( \xi \) and \( \Psi_T \) also decrease, which becomes more important at temperatures below freezing. The consequences are that a single \( \Psi_T \) value cannot be used to reconstruct the temperature, and by keeping the Bragg wavelength query unchanged, a lower temperature sensitivity of the sensor should be expected.

The overhead power line cable temperature measurement and extension system tilted a power line wire, which consists of two fittings, in which there are grooves in the fittings, in which a copper plate with a certain length is stuck, in the copper plate there is a hole in which epoxy resin is poured, an tilted fiber Bragg grating, which is recorded on a multi-mode optical fiber, an optical coupler, an ultraviolet excimer laser and a fiber optic connector, a light power detector.

Line-to-line voltage distribution measurement system using single-mode fiber with a Bragg grating, where the grating is attached to the test object with an adhesive bond, and the deformed spectrum of the deformed grating is measured by a spectrum analyzer, characterized in that the temperature measurement and cable extension system of the overhead power line tilted a wire electric transmission line, which consists of two fittings, while in the fittings there are grooves in which a copper plate with a certain length is stuck, in the copper plate there is a hole in which epoxy resin is poured, attached to an tilted fiber Bragg grating, which is recorded on a multimode optical fiber, which is attached to the optical sleeve, where the light from the ultraviolet excimer laser enters the fiber optic connector and the light power detector.

![Figure 1 - Cable temperature measurement system using fiber Bragg gratings](image)

**Results and discussion.**

Assuming the FBGs are at the same temperature, the Bragg wavelength shift versus temperature can be plotted as shown in FIG. 4. One can easily see some anomalous data for \( \sim 80 \)
K during the cooling process. You can also see that the data during the heating process is slower than the cooling process, since the FBG takes longer to heat up.

![Figure 2 - Wavelength versus temperature](image)

Temperature sensitivity by wavelength is shown in Fig.5. As we can see in this figure, the thermal sensitivity at the Bragg wavelength is less. This can be explained by the lower coefficient of thermal expansion of the shell. Because our FBG fiber was fabricated with a shorter Bragg wavelength than others, we would expect less absolute thermal sensitivity by a fraction equal to the ratio of its Bragg wavelength.

![Figure 3 - Dependence of temperature sensitivity on wavelength](image)

![Figure 4 - Thermal coefficient of the Bragg wavelength](image)
It can be seen from the figure that the sensor indeed has a thermal coefficient that grows exponentially.

Figure 5. The dependence of the coefficient of thermal expansion on temperature

As can be seen from this figure, the coefficient of thermal expansion is defined as the partial increase in length per unit increase in temperature. Over temperature ranges, the thermal expansion of a fiber optic sensor varies proportionally with temperature.

Figure 6 - Temperature dependence of the thermo-optical coefficient

For each temperature test, approximately a full day of measurements was needed. After reaching any operating temperature, the system was maintained in a stable condition for approximately 15 minutes before starting to establish the intensity of the transmitted optical radiation. Five successive and independent measurements of the photodetector output and the corresponding temperature performance values provided by the sensor were further averaged to obtain one pair of measurement points, which took only a few seconds.

Conclusions.
In this study, a cable temperature measurement system was developed using fiber Bragg gratings. The calibration result of the Bragg grating temperature sensor fiber is 0.0634 °C.
Temperature performance experiment shows that the system has high accuracy, good stability and fast response time, and strong anti-electromagnetic interference; it is very suitable for online real-time temperature measurement under high ambient temperature.

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незначительный катетгі 0,0634°C; жүйенің ақауын табу уақыты 3,24 с аспайды. Жұйе жогары өлшеу дәлдігі мен тамаша тұрактылыққа не, накты температуранның өлшеу жүйелеріне бейімделуі мүмкін және бәлгілі бір практикалық құндылыққа не.

Түйінді сөздер. Талшықты-оптикалық сенсор, Браг торлары, температура, кабель.

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СИСТЕМА ИЗМЕРЕНИЯ ТЕМПЕРАТУРЫ КАБЕЛЯ С ПРИМЕНЕНИЕМ ВОЛОКОННЫХ БРЭГГОВСКИХ РЕШЁТОК

Аннотация. В данной статье рассматривается система измерения температуры кабеля с применением волоконных Брэгговских решёток. Система измерения температуры и удлинения кабеля воздушной линии электропередачи включает в себя провод линии электрической передачи, который состоящий из двух штуцеров, при этом в штуцерах имеются пазы, в котором прилеплена медная пластина с определенной длиной, в медной пластине имеется лунка, в которой залита эпоксидная смола, наклонную волоконную решетку Брэгга, которая записана на многомодовом оптическом волокне, оптическую муфту, ультрафиолетового эксимерного лазера и оптоволоконный соединитель, детектор мощности света. Экспериментальные результаты показывают, что погрешность измерения, и погрешность результата калибровки датчика составляет 0,0634°C; время нахождения неполадки системы не превосходит 3,24 с. Система имеет высокую точностью измерений и превосходит стабильностью, может быть адаптирована к реальным системам измерения температуры и имеет определенную практическую ценность.

Ключевые слова. Волоконно-оптический датчик, брэгговские решетки, температура, кабель.

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