

Steel Sleeve Packaged FBG 변형률센서를 이용한 구조물 모니터링에서의 온도보정 기술

Temperature Compensation Technique for Steel Sleeve Packaged FBG Strain Sensor in Structural Monitoring

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ABSTRACT

Due to the fact that bare FBG sensors are very fragile, bare FBG sensor is not properly applied in practical infrastructures as it is not suitable to the rudeness of construction. Therefore packaged FBG sensors are developed for construction application. Since FBG senses strain and temperature simultaneously, temperature compensation for FBG strain sensors is indispensable. In this paper, temperature compensation techniques for steel sleeve packaged FBG sensors are brought forward. And its application on monitoring concrete beam was carried to test the feasibility of the temperature compensation technique. Temperature compensation technique used in this paper is feasible to be extended to structure health monitoring in civil engineering especially in large infrastructures etc.

요 약

피복이 없는 FBG센서는 내구성이 약하기 때문에, 실제 토목구조물에서는 적용이 어렵다. 따라서 packaged FBG센서는 피복이 없는 FBG센서의 단점을 보완하고, 실제 구조물에 적용이 가능하도록 발전된 형태이다. 이런 packaged FBG센서를 이용하여 변형률과 온도를 동시에 측정할 때, 온도보정은 없어서는 안 될, 필수적 기술이다. 이 논문에서는 steel sleeve packaged FBG센서의 온도보정 기술을 도출하고, 콘크리트 보부재를 이용한 실험을 통해 온도보정 기술의 현장적용 가능성을 제시하였다. 따라서 이 논문에서 사용된 온도보정 기술은 실제 여러 토목구조물의 모니터링에 확대 사용할 수 있다.

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1. Introduction

FBG strain sensor has now been widely investigated and applied in infrastructures, since Hill and Meltz developed the FBG fabrication techniques. However, due to the fact that bare FBG sensors are very fragile, bare FBG is not properly applied in practical infrastructures directly because it can not adapt to the rudeness of construction. Therefore packaged FBG sensors are developed for construction application. Since FBG senses strain and temperature simultaneously, for accurate measurement of strain, temperature compensation for FBG strain sensor is indispensable. Many researches have been done on temperature compensation methods of FBG sensors, which include dual-parameter measurement [1], opposite temperature expansion materials [2], Chirped Bragg grating [3], etc. Considering the complex fabrication of these methods, they are not suitable for practical applications. In this paper, the temperature compensation technique for steel packaged FBG sensors are brought forward. And its application on monitoring concrete beam was carried to test the feasibility of the temperature compensation technique.

2. Sensing Mechanism of FBG on Strain and Temperature

When broadband light passes through the FBG, the narrowband spectral component at the Bragg wavelength is reflected by the FBG. The basic principle of FBG's is to measure the shift of reflected Bragg wavelength (λ_B), which is related to the effective refractive index (n_{eff}) and the periodicity (Λ) of the index variation of the grating area in fiber core. The Bragg wavelength is given by the expression:

$$\lambda_B = 2n_{eff}\Lambda \quad (1)$$

The shift of Bragg grating wavelength due to strain can be expressed as

$$d\lambda_B = \lambda_B(1-P)\varepsilon = \alpha_\varepsilon\varepsilon \quad (2)$$

where α_ε is strain sensitivity of fiber Bragg gratings. When FBG affected by temperature, the shift of Bragg grating wavelength due to temperature can be shown below:

$$d\lambda_B = \alpha_T dT \quad (3)$$

Where α_T is temperature sensitivity coefficient of fiber Bragg gratings. If fiber Bragg grating is subject to strain and temperature simultaneously, the wavelength shift can be express as

$$d\lambda_B = \alpha_\varepsilon\varepsilon + \alpha_T dT \quad (4)$$

3. Temperature compensation for steel sleeve packaged FBG strain sensors

In the practical application of FBG sensor in civil engineering, protection measures ought to be done due to the fragility of bare FBG sensor. Generally, bare FBG is encapsulated in steel sleeve. Once bare FBG sensor is encapsulated by steel sleeve, its thermal performance will change when subject to stress together with the structures that it measures. Following, the Bragg wavelength shift of embedded-steel sleeve packaged FBG strain sensor under co-action of stain and temperature is derived.

As temperature difference dT occurs, the interactive force F will happen between fiber and steel sleeve due to their different TEC. The strain of steel sleeve can be expressed as:

$$\varepsilon_s = -F/(A_s E_s) + \alpha_s dT \quad (5)$$

where A_s is the cross-section area of steel sleeve, E_s is its elastic modulus, and α_s is its

TEC. Correspondingly, the strain of fiber ϵ_f is:

$$\epsilon_f = (F / A_f E_f) + \alpha_f dT \quad (6)$$

where A_f is the cross-section area of fiber, E_f is its elastic modulus, and α_f is its TEC. As the deformations of steel sleeve and fiber are compatible, i.e., $\epsilon_s = \epsilon_f$, combined it with Eqs.(5) and (6), F can be solved as Eq.(7) below:

$$F = (\alpha_s - \alpha_f) dT \frac{A_s E_s A_f E_f}{A_s E_s + A_f E_f} \quad (7)$$

Substitute Eq.(7) into Eq.(6), then can be obtained as Eq.(8):

$$\epsilon_f = (\alpha_s - \alpha_f) dT \frac{A_s E_s}{A_s E_s + A_f E_f} + \alpha_f dT \quad (8)$$

As $A_s E_s \gg A_f E_f$, Eq.(8) can be rewritten:

$$\epsilon_f = \alpha_s dT \quad (9)$$

According to Eq. (9), fiber strain due to temperature change is determined by the thermal performance of the steel sleeve. When FBG is embedded in concrete structure, thermal deformation of fiber itself due to temperature can be neglected as its thermal expansion coefficient (TEC) is similar with that of concrete. Therefore, fiber strain due to temperature is thought as the concrete thermal strain.

The wavelength shift of FBG embedded in the concrete structures is composed of two parts: (1) due to structural strain, which includes structural strain subject to loading and the structural strain $\alpha_c dT$ due to temperature change dT , where α_c is the TEC of concrete. (2) due to temperature varying. As shown below:

$$d\lambda_B = \alpha_\epsilon (\epsilon_0 + \alpha_c dT) + \alpha_T dT \quad (10)$$

For temperature compensation for FBG strain sensor, a FBG temperature sensor is placed in the vicinity of it, which only responds to the temperature change. Under the co-action of structural strain and temperature varying, wavelength shift of FBG strain sensor and that of FBG temperature sensor are shown as below:

$$\begin{cases} d\lambda_{B1} = \alpha_{\epsilon 1} \epsilon + \alpha_{T1} dT \\ d\lambda_{B2} = \alpha_{T2} dT \end{cases} \quad (11)$$

By solving Eq(11), we can get

$$\epsilon = \left(d\lambda_{B1} - \frac{\alpha_{T1}}{\alpha_{T2}} d\lambda_{B2} \right) / \alpha_{\epsilon 1} \quad (12)$$

Introducing $\epsilon = \epsilon_0 + \alpha_c dT$ into Eq.(12), then can be got as:

$$\epsilon_0 = \left(d\lambda_{B1} - \frac{\alpha_{T1}}{\alpha_{T2}} d\lambda_{B2} \right) / \alpha_{\epsilon 1} - \alpha_c dT \quad (13)$$

Based on above equation (12) and (13), we can get the accurate strain from the measured FBG wavelength easily.

4. Application on the early age property monitoring of concrete beam

High-rise apartment construction works are built in Yongin City. And the measured beam is cast by ready-mixed HPC. Steel-tube packaged Embeddable FBG strain sensor and FBG temperature sensor is used in this research, and they are embedded in the mid span of the

beam before concrete pouring. In the early age of concrete pouring, concrete temperature varies much rapidly as shown in Fig.1(a) from FBG temperature sensor due to the large amount of hydration heat released by cement hydrating. Fig.1(b) shows the concrete strain varying curves before and after temperature compensation, which illuminates that temperature compensation for FBG strain sensor is imperative to get accurate strain data especially when temperature changes greatly. As there is no loading on the concrete beam at the early age, so the total strain of concrete includes:

$$\varepsilon = \varepsilon_{shrinkage} + \alpha_c dT \quad (14)$$

where after initial setting is adopted as $1.3 \times 10^{-5}/^{\circ}\text{C}$. In the early age time and within the short period, drying shrinkage and carbonation shrinkage are considered negligible. Therefore $\varepsilon_{shrinkage}$ only includes autogenous shrinkage. According to Eq.(14), concrete autogenous shrinkage and thermal strain can be got as shown in Fig.1(c), which shows much high autogenous shrinkage within the early age of HPC.

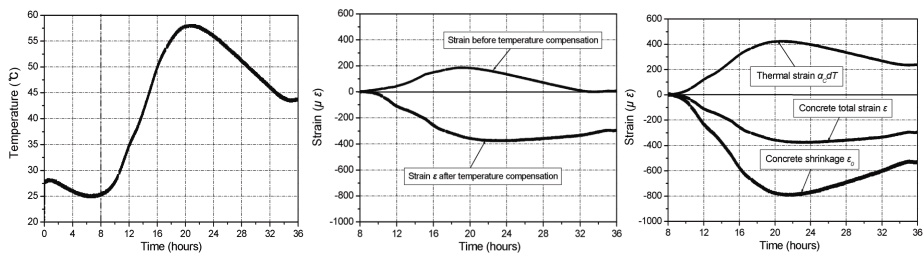


Fig.1 (a) Temperature varying curve (b) Concrete beam strains (c) concrete thermal strain and shrinkage

5. Conclusions

Based on the FBG's strain and temperature sensing principles, the temperature compensation techniques for steel sleeve packaged FBG sensors are put forward. And the application on early age monitoring of HPC beam by dual FBGs verified the feasibility of the temperature compensation technique. Meanwhile, the results show that in the early age of concrete pouring, temperature compensation for FBG strain sensor is urgently imperative to get accurate concrete strain measure as temperature changes greatly.

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References

1. Xu M.G., Archambault J.L., Reekei L. ,et al. "Discrimination between strain and temperature effects using dual-wave length fiber grating sensors", Electronics letters, 1994, 30 (13): 1085-1087
2. T.Iwashima , et al. "Temperature compensation technique for fiber Bragg grating using liquid crystalline polymer tubes", Electronics letters, 1997, 33 (5): 417-419
3. M. G. Xu, et al, "Temperate-independent strain sensor using a chirped Bragg grating in a tapered optical fiber", Electronics Letters, 1995, Vol.31: 823-825