The Research to Monitoring System of Wuhan Yangluo Yangtze River Bridge's Anchorage System

LIU SHENG-CHUN[1]

ABSTRACT:

It is vital to monitor the condition of suspension bridge's anchorage and main cable, which is the key to whole suspension bridge. In this paper, a innovative Load Cell based on fiber Bragg gratings (FBG) was researched and developed, and applied to measuring and monitoring a bridge's anchorage system for a long term. This type of suspension anchorage is the first time to utilize to practical bridge engineering system Wuhan Yangluo Yangtze River Bridge in Wuhan China. That is the So-Called the non-cohesive and replacive prestressing anchorage characterized by alternative according to monitoring the tension state.

KEY WORDS: Wuhan Yangluo Yangtze River Bridge; prestressing anchorage; Load Cell (test-force ring) based on FBG; long-term monitoring

1 INTRODUCTION

The anchorage is very important in all of the stress structure parts of suspension bridge. Traffic load and self-weight of superstructure conducts through the main cables to the main towers and anchorage system, and then to the foundation. Therefore, suspension bridge's anchorage system of the main cables is vital to whole suspension bridge structure. The Wuhan Yangluo Yangtze River Bridge is a 250m+1280m +440m river-span project, which will be the crucial segment of both JingZhu and HuRong national highway, and the northeast part of Wuhan city circle highway[1].

At present, main cables anchorage system of suspension bridge in China usually uses coherent anticorrosive prestressing system by pressing cement into pipeline, which leads to the structure permanent and un-exchangeable. Moreover, it is not easy to ensurethe construction quality of grouting. In order to ensure safety and durability of anchorage system even the whole bridge service life radically, the designer innovatively utilize non-cohesive and replacive prestressing anchorage system. It is acorringly put

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forward that a research subject about chronically monitoring prestressing of anchorage system, which provides warranty for replacing the prestressing system by monitoring the tension condition of suspension bridge anchorage system for long term. It is consequently vital to chronically monitor tension of prestressing system reliably.

However, such conventional methods of measuring tension of prestress system as electric resistance strain gauge, vibrating-string load cell could only be used for short-term measurement. Therefore, the problem developing new-style load cell must be solved for implementing long-term monitoring of prestressing system characterized by non-cohesive and replacive.

This paper will focus on the development and application of load cell based Fiber Braag Grating(FBG). This type of sensing and measuring technology has a lot of remarkable advantages[3],such as tiny capacity,good corrosion resistance, anti-interference to electromagnet, long-term reliability, high-accuracy digital transducing and distributed measuring, which have hugely contributed to civil engineering, and become important foundation of developing the new-style load cell. In practical application, used experience of existing vibrating-string load cell for reference, The innovative load cell based FBG will be developed for monitoring prestressing anchorage system long-term and on line. The changes of magnitude and distribution of prestress will accoringly reflect safety of whole bridge structure directly.The data chronically gathered will be significant parts for knowing health condition of the suspension bridge in Health Monitoring Syetem and Digital Management of Wuhan Yangluo Yangtze River Bridge.

2 THE STRUCTURE OF SUSPENSION OF BRIDGE ANCHORAGE SYSTEM

At present, the suspension bridge anchorage system that has been established in the world usually adopts prestressing steel-stranded-wire anchorage. According to design and construction experience of anchorages of many established suspension bridges, prestressing anchorage system usually uses grouting that bumping cement into pipeline, which is cohesive prestressing system leading to the structure permanent and un-exchangeable.Sometimes,the rust-proof and durability of prestressing steel stranded wire was badly affects due to construction quality. In order to ensure safety and durability of anchorage system of Wuhan Yangluo Yangtze River Bridge, designer developed the non-cohesive and replacive prestressing anchorage system[1].

As shown in Figure 1. The component of anchorage system is composed of the joint structure of cable strands anchorage and the structure of prestressing steel bundle anchorage. The joint structure of cable strands anchorage is composed of coupling, drawbars and their components, while the structure of prestressing steel bundle anchorage is composed of pipelines, prestressing steel stranded wire, anchor device, antiseptic grease, anchorage helmets and so on. The upper end of drawbar is connected with anchor plate on cable strand anchorage, and the other end is connected with the coupling that is fixed on front anchor by prestressing steel bundle anchorage. The coupling is made up of coupling flat plate and coupling reel, which makes coupling designed by components, makes anchorage stress definitely, and makes it convenient to product, transport and install.

The prestressing steel bundle between the front side and the back side of anchor is non-cohesive prestressing system.The reason for why his type of anchorage was called non-cohesive and replacive prestressing anchorage system is that the steel stranded wire will not be grouted in the pipeline filled with antiseptic grease, and characterized by non-cohesive.The stretching end of anchor was remained additional length which suffice the replacement of stell stranded wire, According to design conception of the anchorage system, we need to install pressure sensors on anchorage link parts of the anchorage system to the effect that engineer can monitor stress state of the cable strand at any time in bridge's service period.

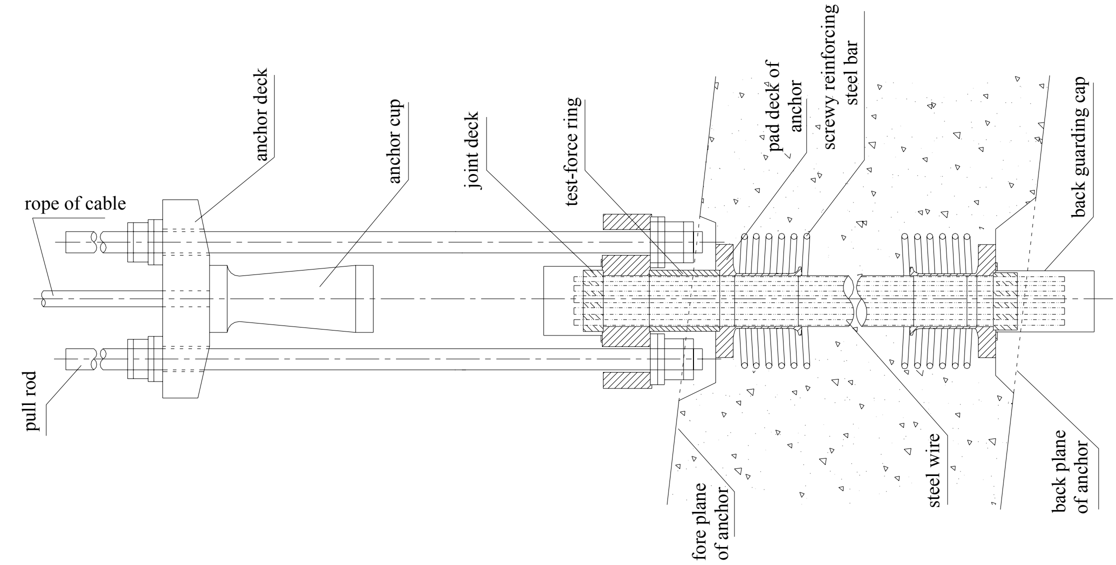

Figure 1: chart for Wuhan Yangluo Yangtze River Bridge

In practical application, The load cell(test-force ring) based FBG is regarded as alternative of gasket, which is installed between the front side of anchor and coupling flat plate. So, measuring surplus prestressing of anchorage system and calculate stretching force of cable strand can be deal with in once without accessory structure to the anchorage system.

3 THE DEVELOPMENT OF FIBER GRATING LOAD CELL [2]

3.1 The Theory of Fiber Grating Sensing

Fiber Bragg Grating (FBG) is the commonest fiber grating sensor, its basic principle as shown in Figure2. When the temperature, strain or other physical quantity which can be transferred to temperature or strain change, the grating period Λ(we call it raster unit) will change, so wave center length of FBG will excursion. And through the monitoring of wavelength excursion, we can apperceive change of physical parameter being measured.

The change of FBG wavelength caused by strain can be expressed.

$$\Delta\lambda_B / \lambda_B = (1 - P_e)\varepsilon = K_\varepsilon \cdot \varepsilon \quad (1)$$

Where P_e is the elasto-optical coefficient of fiber, λ_B is the center wavelength of FBG without strain, $\Delta\lambda_B$ is the wavelength displacement caused by strain, ε is the applied axial strain and K_{ε} is the relative strain sensitivity coefficient of FBG. The change of FBG wavelength caused by temperature.

$$\Delta\lambda_B / \lambda_B = (\alpha + \xi)\Delta T = K_t \cdot \Delta T \quad (2)$$

where α is the thermal expansion coefficient of FBG, ξ is the thermo-optical coefficient, ΔT is variance of temperature and K_t is the relative temperature sensitivity coefficient of FBG.

From the analysis above, we can know that there is good linear relationship

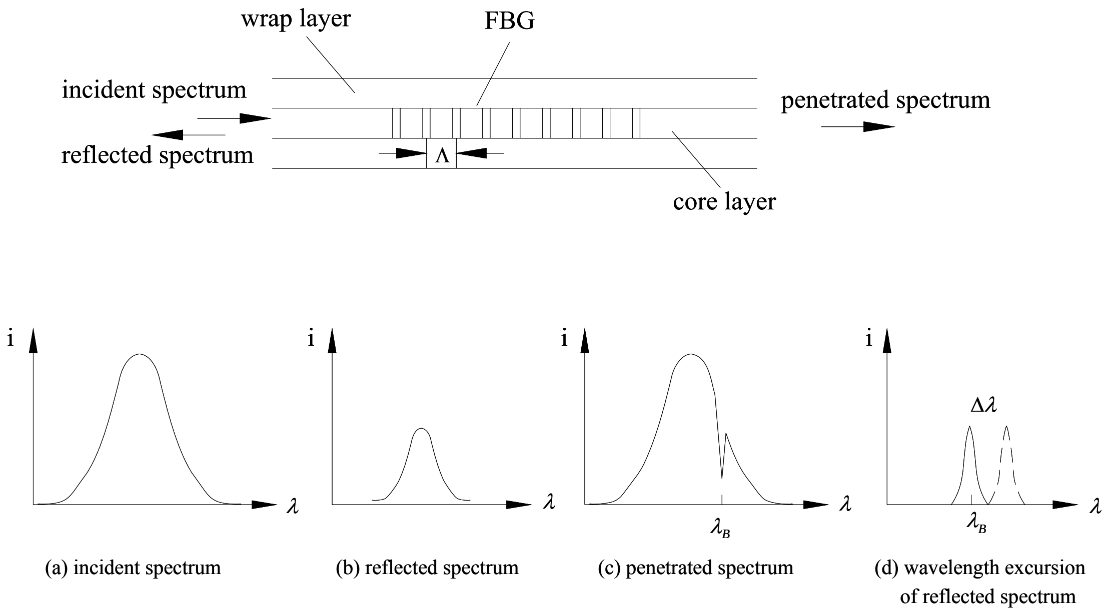

Figure 2: sensing principle of FBG

between wavelength, strain and temperature change. According to the reference literature, it is approximately independent between the temperature and the strain influence of FBG wavelength when the temperature ranges between 0°C and 100°C, and the strain is in the range of 0 to 10000 $\mu\varepsilon$.

Another advantage of FBG sensor is the wavelength division multiplex (WDM) technology actualized distributed sensing measure. In other words, we can use the same fiber concatenated many FBG to measure strain, temperature and other parameters simultaneity. Figure 3 shows multiplex sensing measure principle of FBG. (λ_1, λ_2, $\cdots$, λ_n) is the FBG center wavelength, which is corresponding with different measuring points. Each FBG is influenced by temperature or strain, and wavelength shift occurs nearby λ_i of each FGB.In strain measuring, the effect to measuring result caused due to temperature change can be eliminated by using the principle of multiplex measuring and linear superimposed relationship of sensors.

Sensing principle above of the FBG sensor and characteristic of fiber material itself bring about long-term reliability of sensing system. Therefore, FBG sensor is generally regarded as ideal device that can realize ‘fiber smart structure’ and ‘fiber smart material’, and it is widespread used in safety monitoring of aerospace vehicle, bridge structure, ship structure, building structure, nuclear power plant and so on.

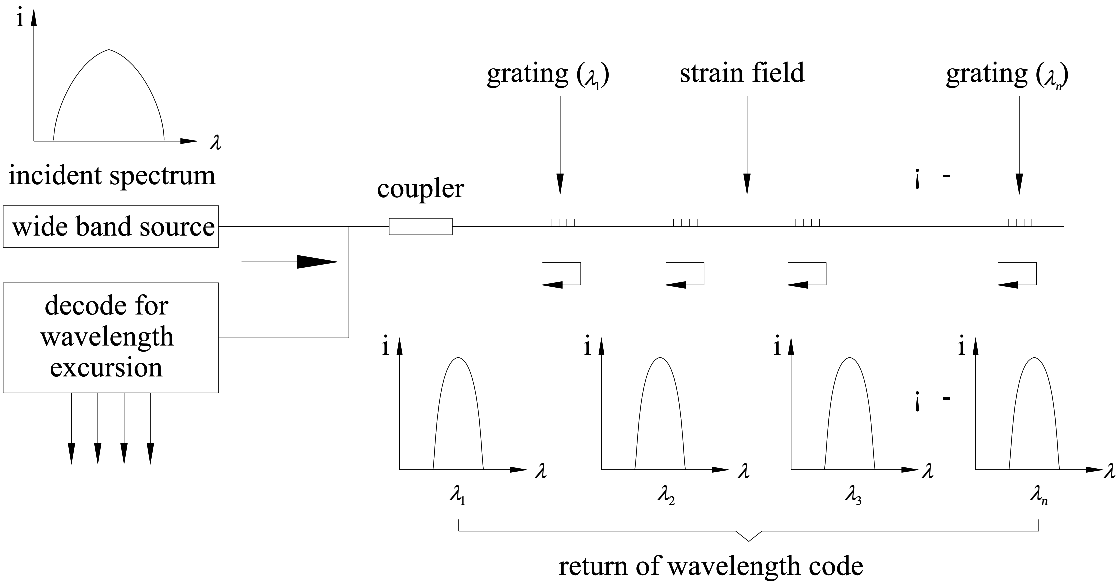

Figure 3: multiplex sensing principle of FBG

3.2 Load Cell Based on FBG[2]

Load cell(also called test-force ring) is the main method of measuring tension of bridge cable directly. There are three structural styles of force cell which are spoke-type, ring-type and hydraulic. Sensing principles used for traditional force cell are mainly differential resistance type, vibrating-string-type, electric resistance strain type and so on. Because traditional measuring technology is deficiency in tolerance to abominable environmental and long-term reliability, a innovative Load cell based on FBG was developed on the purpose of bridge health monitoring system.

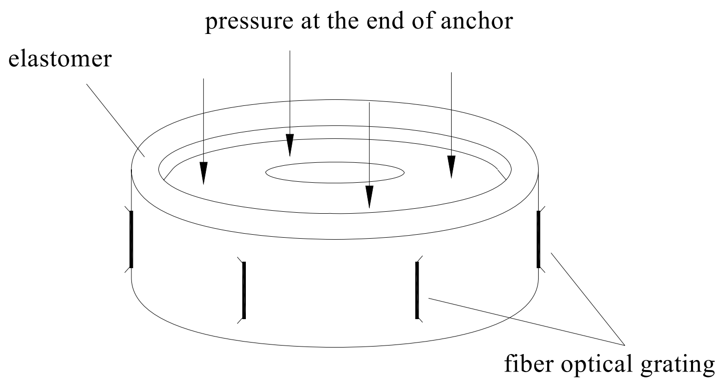

Figure 4: Prototype of Load cell based FBG

The prototype of Load cell as shown in Figure 4. Four FBG strain sensors connected in series with a temperature sensor are evenly arranged axially on the annular alloy elastomer (material 40CrNiMo). The whole structure is formed an independent unit in order to afford facilities with construction.

According to the sensing principle of FBG, we evenly divide elastomer and n FBGs into n parts correspondingly. Equation (3) determines the relationship between test load stress of load cell of BFG and wavelength of each strain sensor.

$$F = \sum_i F_i = K_\lambda \cdot \sum_i \frac{\Delta\lambda_i}{\lambda_i} + K_T \cdot \Delta T \tag{3}$$

Where parameter K_λ and parameter K_T can be expressed by equation (4) and equation (5) respectively:

$$K_\lambda = \frac{E \cdot \Delta S}{1 - p_e} \tag{4}$$

$$K_T = -K_\lambda(\alpha + \xi) \tag{5}$$

Where E is Young's modulus, ΔS is area of stress section of elastomer's corresponding part.

According to what we explained above, we can work out the total load of elastomer if we know the wavelength displacement of each FBG and its variance of work temperature. We can get parameter K_λ and parameter K_T which are related to Young's modulus and thermal expansion coefficient of elastomer by calibrating.

To sum up, Load cell based FBG characterized by: (1) The excellent Signal-to-Noise of measurement, high sensitivity and accuracy,and good long-term reliability; (2) The temperature measuring and self-compensation by multiplex sensing;(3) The independent part and convenient installation ; (4)The remote monitoring of tension conveniently.

4 FIELD MEASURING AND INTERPRETATION OF LOAD CELL

4.1 Construction and Installation of Load Cell

In main cable anchorage system of Wuhan Yangluo Yangtze River Bridge, there are 94 anchorage cables(include 34 single-cable and 60 double-cable anchorage cables) both upstream and downstream on south bank. While 98 anchorage(include 34 single-cable and 64 double-cable anchorage cables) both upstream and downstream on north bank.

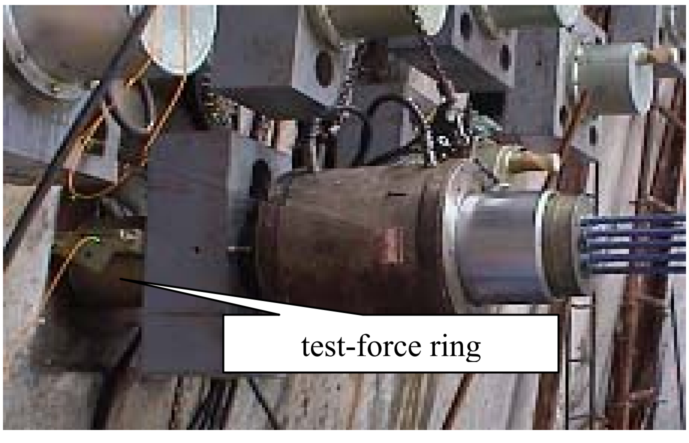

Figure 5: field installation of test-force ring of FBG

According to the overall design scheme of long-term health monitoring system by experts repetitious evaluation, Some 12 of them representativ prestressing anchor were chosen to measure the cable tension of anchorage system by installing test-force rings. Namely, 8 for single cable anchor (serial number from $1^{\#}$-$8^{\#}$) and 4 for double cable anchor (serial number from$9^{\#}$-$12^{\#}$). The installation of load cell on-site as shown in Figure 5. The test-force rings were installed between the fore plane of anchor and joint flat plate before being tensioned. According to design criterion, the control tension(T_1) of single cable anchor of is 300.3 ton, while the control tension(T_2) of double cable anchor is 582.1 ton. The full procedure of tension include three levels (15%T , 30%T , 103%T).

The Load cell of anchorage system of Wuhan Yangluo Yangtze River Bridge had been installed in June 2005, and the data was tested when each prestressing anchorage was tensioning. In this paper, we mainly analyze data acquired before spaning all of main cable strands.The test process contain when prestressing anchorage cables are tensioned and periodic tests of temperature influence after installation.

4.2 Interpretation of Test Result

Tension load is imposed on anchorage by the hydraulic jack , and the load is controlled by indication reading of oil pressure guage. The test result of cable tension was read and processed on site by transmiting signal from load cell to portable demodulator. Once collecting wavelength signal of sensors, the computer calculated load of test-force ring according to calibration data. While noted document reading of oil pressure gauge, extension length of anchorage cable and measuring data of load cells after each level have been finished.

The the contrast between test data for $9^{\#}$ load cell and theoretics controlling reading during tensioning process as shown in Table 1. The relative difference between cable tension acqurired by load cell and controlling reading is -1.8%, which is the largest different in all 12 load cells. The result indicates that the measuring accuracy of load cells is very high, which can entirely satisfy the measuring error(less than ±2.0%).

Table 1: the result data of $9^{\#}$ test-force ring

tension level	theoretic value		measuring value						difference cable force (%)
	hydrau pressure (Mpa)	cable force (t)	hydrau pressure (Mpa)	test-force ring value(t)					
				FBG1	FBG2	FBG3	FBG4	aver.	
15% T_2	6.6	84.8	6.6	83	82	85	84	83.5	-1.5%
30%T_2	12.9	169.5	12.9	165	160	177	170	168	-0.9%
103%T_2	43.7	582.1	43.7	565	559	595	584	576	-1.1%
reversio	0	557.1	0	540	527	565	555	547	-1.8%

After installation data measured lasting for two month was processed between September and November in order to understand the relationship between cable tension and anchorage temperature. We choose test data of single-cable-strand($1^{\#}$ and $3^{\#}$) and double-cable-strand($9^{\#}$ and $11^{\#}$) load cell to analyze the contrast relatives between cable force and temperature of load cells.The test data curve as shown in Figure 6.

Where cable force is the total prestress after calculating average measuring data of 4 FBG strain sensors,and temperature is the measuring value of temperature FBG sensor capsuled in load cell. We can explain that the relationship between cable force and temperature is reverse from this charter. In other words, the higher temperature is, the tension of cable is smaller, and vice versa. This rule is consistent with the analysis results when applied theory of thermodynamics,and must be taken account for when we measure tension of cable under different temperature conditions.

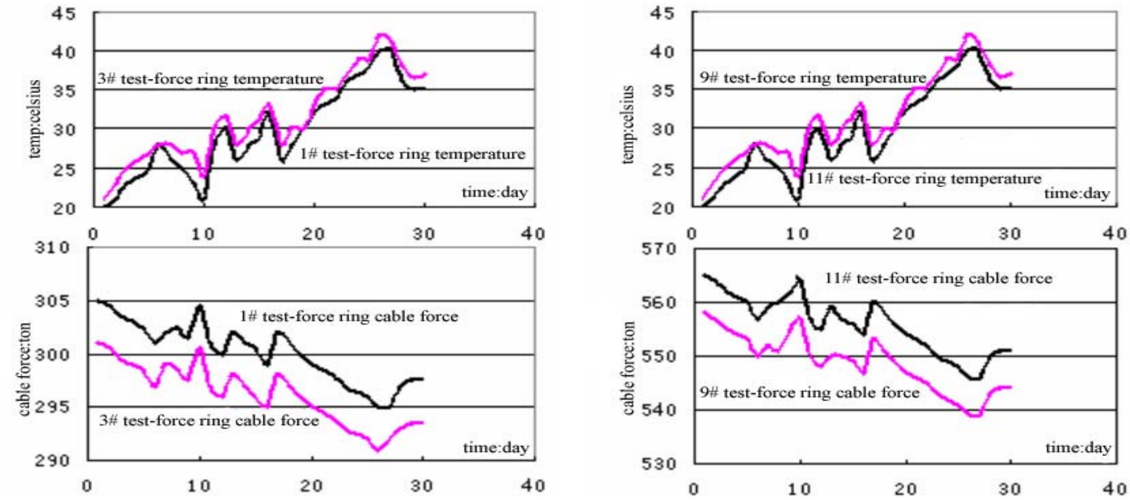

Figure 6: Curve of cable tension with temperature

5 CONCLUSIONS

The load cell based FBG developed specially had been successfully utilized in anchorage prestressing monitoring system of Wuhan Yangluo Yangtze River Bridge. The tension process test indicates that the accuracy of the load cell of FBG is very high(less than ±2.0%), and the temperature influence test indicates that cable tension changes regularly along with the temperature changes.These results verified that the type of load cell is suitable for chronically monitoring anchorage prestressing system. In subsequent construction of main cable of this bridge, we can further monitor variance regulation of anchorage cable force by utilizing these load cells installed.With the accumulation of long term monitoring data the replacive warranty of new-type non-cohesive and replacive prestressing anchorage system of suspension monitoring will be setup.

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