Design of an Intelligent Optical Fiber Grating Temperature Measurement System for Electrical Equipment

Liping Zhang*
Wuhan Railway Vocational College of Technology, Wuhan 430205, Hubei, China

*Corresponding author e-mail: zhangliping@wruc.edu.cn

Abstract. Today, domestic temperature monitoring systems usually use a master-slave multi-computer network composed of personal computers and single-chip computers. The single-chip microcomputer is used as a sub-computer to collect the temperature data of each sampling point. As a desktop computer, the PC is responsible for recording and displaying temperature and humidity, and centralized management. Since the conventional temperature measurement system cannot detect wavelength changes well, the temperature measurement system has problems such as low accuracy and stable operation. Therefore, an intelligent optical fiber grating temperature measurement system design for electrical equipment. The structure and characteristics of fiber grating and the principle of automatic temperature measurement of fiber grating components are introduced. Following the above principles, the temperature measurement system architecture is designed to include a data viewing layer and a remote monitoring layer in the storage layer. The results show that the total temperature change caused by the electrical equipment failure of the system described in this article is less than 1°C, and the total temperature change of the designed system is in the range of 2.5 to 3.5°C. The results show that the temperature error of the system described in this document is very small, and can accurately measure the automatic temperature of the glass fiber grid of electrical equipment.

Keywords: Electrical Equipment, Optical Fiber Grating Sensor, Intelligent Temperature Measurement System, Optical Fiber Temperature Converter

1. Introduction

1.1. Background and Significance
The grid fiber uses the photosensitive characteristics of the fiber material to form the spatial topological lattice of the fiber core. The essence is to create a narrowband filter or mirror image for the core [1]. This function can be assembled with new passive components to be used as an energy-saving light source, but the optical fiber itself makes full use of the advantages of low power transmission, electromagnetic interference, light weight, small size and strong flexibility [2]. Domestic temperature monitoring systems usually use a master-slave multi-computer network composed of personal
computers and single-chip computers. The single-chip microcomputer is used as a sub-computer to collect the temperature data of each sampling point. Optical fiber grid provides a variety of applications for optical fiber communication, optical fiber inspection and optical calculation [3]. Various sensors are widely used in various fields. Optical fiber grid detection technology is a new type of sensor, which uses optical fiber grid as the sensor element, pointing out the direction for the development of the next generation of optical sensors [4]. Fiber optic grid sensors are currently used in many industries in Korea. The petrochemical industry uses the Prague Textile Network's temperature warning system to monitor oil depots.

Sensor technology is the most advanced and one of the main areas of modern information technology. The sensor industry has attracted the attention of the world due to its high technical content, excellent economic benefits, strong penetration rate and various market opportunities [5]. It can be changed according to the state of transmitted light, incident light, reflected light and related energy [6]. By combining the relationship between the axial tension of the fiber and the change of the wavelength of the fiber grating, the most basic is that it is not only closely related to people's daily life, but also closely related to the ambient temperature. However, real-time temperature measurement of industrial production is still necessary, and there is no difference from temperature measurement of agricultural products [7]. Paper, textile and other industries need to measure temperature at multiple locations on the surface of the drum [7]. Therefore, it is very important to study temperature measurement methods and test components. An important method of measuring temperature is the use of temperature sensors. This article uses fiber grating temperature sensors to measure temperature and humidity.

1.2. Related Work
Temperature is a very important parameter in the industrial production process and needs to be studied carefully through research and optimization. However, in some industries, FBG applications where existing electrical sensors cannot work properly are ideal. Diaz-Alvarez J believes that the system can adjust the fiber grating sensor at a high speed, but the temperature error is large, and it cannot accurately complete the automatic temperature measurement of the fiber grating of electrical equipment. Therefore, the development of optical fiber detection systems that can be applied to sensor temperature plays a very important role in industrial production. This improves the detection of automation, can increase the degree of automation of system detection and produce huge economic benefits [8]. Yuntao proposed "a design of an intelligent optical fiber grating temperature measurement system for electrical equipment". Its purpose is to design and develop an intelligent electrical equipment optical fiber suitable for engineering applications with high precision, low price, convenient operation, and real-time display of detection target parameter changes [9].

1.3. Main Content
Through learning the basic knowledge of fiber grating, and analyzing the current development history of fiber grating temperature measurement, based on consulting a large number of literature materials, this paper has conducted the following research:

The first chapter mainly introduces the development and current situation of this fiber grating sensing technology and the research purpose, significance and related work of the paper.

The second chapter introduces the research method of optical fiber grating temperature measurement system for intelligent electrical equipment.

The third chapter introduces the automatic temperature measurement system, analyzes the structure and characteristics of fiber grating and the principle of fiber grating automatic temperature measurement, and describes the hardware design and software design of the system.

The fourth chapter introduces the analysis of experimental data, and gives a detailed introduction to the simulated temperature test experiment.

The fifth chapter summarizes the specific work of this thesis and makes a prospect for the next step.
The innovation of this paper is that the system hardware adopts FTM3501 optical fiber temperature converter, adopts a temperature sensor designed by independent packaging, and realizes wavelength demodulation based on tunable optical fiber FP filtering method, which can be provided to a computer or data collector for processing to realize optical fiber The function of grating automatic temperature measurement.

2. Two Research Methods for the Design of Optical Fiber Grating Temperature Measurement System for Intelligent Electrical Equipment

2.1. Structured Analysis Method
The basic concept of the structured analysis method is the performance degradation caused by moving from top to bottom. Classification and abstraction are the two basic ways people use the complexity of a problem. For complex issues, it is difficult to investigate all aspects and details of the problem. Usually, a big problem can be divided into thousands of small problems. Each small problem can be broken down into several small problems. After some falls, the lowest problem is easy to solve, so even complex problems can be solved easily. This is a process of deterioration. In general, oak tree structure analysis technology is a top-down modeling technology, which relies heavily on data flow curves and requires analysis technology. However, this is also an effective technical means to standardize overall requirements.

Working steps of structured analysis:
(1) Physical Environment
First of all, a data flow diagram of the current system should be made to illustrate the input and output data flow of the system, explain the data flow of the system, and what processes have been experienced, as shown in Figure 1.

![Diagram](image)

**Figure 1.** The architecture of the automatic temperature measurement system

(2) System Principle Analysis.
The fiber web is the main component, a fiber made of delicate materials. Due to the unique role of photosensitive fibers, when a lateral event occurs using ultraviolet lasers, the refractive index of the fiber core increases. There may be a structure in which the refractive index changes periodically. It can be changed according to the state of transmitted light, incident light, reflected light and related energy. By combining the relationship between the axial tension of the fiber and the change of the wavelength of the fiber grating, the functional relationship between the physical quantities can be established.

2.2. Data Comparative Analysis Method
Usually, data analysis is performed after collecting experimental data. For example, after analyzing a large amount of collected data using appropriate statistical analysis methods, extract useful information for summary, conduct a comprehensive survey and summarize the data. This method is
used to compare data. For the optical fiber network temperature measurement system and electrical equipment system used in this article, Lu Jianzhong proposed and designed an automatic optical fiber network measurement system for electrical equipment using Catadio Pro’s thermally stable probe sensor. It is an experimental data that focuses on the intelligent temperature measurement system. Advantages in optical fiber networks (electrical equipment studied in this article).

3. Experiment of Optical Fiber Grating Temperature Measurement System for Intelligent Electrical Equipment

3.1. Automatic Temperature Measurement System Architecture
The optical fiber grating temperature measurement system for intelligent electrical equipment combines different lattice constants in a single fiber. Broadband Y splitter for broadband transmission through the light source and the entire fiber optic network. There is a slight difference in the wavelength reflected by another fiber carbon connected to the controller connected to the Y splitter.

According to the requirements of the paper, the system is divided into layers:
(1) Data collection layer
(2) Data monitoring layer
(3) Remote monitoring layer

The temperature data obtained from the monitoring is packaged, and then sent to the computer monitoring center through the network, so that the remote temperature monitoring of the optical fiber grid of the electrical equipment can be realized.

3.2. Hardware Design of the System
The system uses the hardware FTM3501 optical fiber temperature converter, which is an optical fiber temperature decoding module, is a single channel, can generate 4 to 20 mA industrial standard power, and process optical fibers. A computer can be created for it, or it can be provided to a data collector.

The performance of the fiber grating is very good, the reflectivity is high, and the bandwidth is less than 0.2mm. The expression of the reflection wavelength corresponding to the peak is as follows:

$$\lambda_{bg} = 2n_{eff} \Lambda$$

(1)

Among them, \(\Lambda\) is Grating period, \(n_{eff}\) is Effective refractive index, Suppose the axial strain is \(\xi\), the temperature is \(T\), the relative change in wavelength is

$$\Delta \lambda B / \lambda B = (\alpha + \xi) T + (1 - P_e) \xi$$

(2)

\(\alpha\) is thermal expansion coefficient of fiber grating, \(\xi\) is thermo-optical coefficient, usually, \(\alpha = 0.55 \times 10^{-6}, \xi = 8.3 \times 10^{-6}\). The temperature of the electrical fiber grating at work and the amount of strain at work are obtained.

In order to improve the sensitivity of the temperature sensor in the system, the sensitivity of the sensor in the system is increased by sensitizing materials. The temperature sensitivity can be expressed as:

$$M_T = ((\alpha + \xi) + (1 - P_e)(\alpha_j - \alpha))\lambda_{bg}$$

(3)

3.3. System Software Design
The system software is divided into three parts: single-channel measurement, 4-channel measurement and data playback. It consists of four parts: 4-channel measurement, wavelength measurement, measurement, spectrum analysis, alarm, threshold and parameter settings. The measurement frequency of single-channel measurement can reach 4Hz. If you want to measure four channels at the same time, the measurement frequency of each channel is only 1Hz, so you can choose according to your needs.
The playback function will run under non-sampling conditions. In other words, pressing the ← key will disable the playback function and only allow you to use other functions, otherwise you can play. But other characteristics are not accurate. You can use complex measurement methods to measure the measured physical quantity on the optical fiber in a variety of sizes. You can measure physical quantities. (Real-time, strain, pressure, etc.) are measured during real-time data collection. Unlike other physical quantity correction factors, the calibration factor also depends on the sensor. Similarly, the initial scale value and the wavelength setting of other parameter settings allow simultaneous measurement of other physical quantities.

4. Experimental Results and Analysis

We will compare the system developed in this article with the system that measures the temperature of the optical fiber network of ordinary electrical equipment, and compare the temperature errors of the two systems. The comparison results are shown below.

The equipment comparison is shown in Table 1:

| System          | PLC          | Sensor                     | PC          |
|-----------------|--------------|----------------------------|-------------|
| S7-300PLC       | OPTIC3001    | Have                       | FTM3501     |
| Ordinary System | OPTIC3001    | No                         | FTM3501     |

The results of the comparison data are shown in Figure 2:

![Figure 2. Date comparison digram](image)

The temperature error test confirmed the compatibility of the wavelength data of the optical fiber network with the actual data. The higher the matching degree, the more stable the system. As described in this article, the system is compatible with the optical network temperature measurement system for electrical equipment. Lu Jianzhong proposed and designed a temperature measurement system for electrical equipment automation optical fiber network based on refractive index, and achieved a star sensor. The test result is shown in Figure 3.
Figure 3. Comparison of data fitting of wavelength changes in different systems
Compared with the common system and literature system, the results are shown in Table 2:

| Number of Experiments/Time | System/s | Ordinary System/s | Documentary System/s |
|---------------------------|----------|-------------------|---------------------|
| 10                        | 3.2      | 15.1              | 10.1                |
| 20                        | 3.4      | 14.6              | 9.8                 |
| 30                        | 3.3      | 15.3              | 11.2                |
| 40                        | 3.6      | 16.1              | 10.5                |
| 50                        | 3.7      | 15.7              | 10.3                |

It can be seen from the analysis of Table 2 that the time-consuming of the two systems is higher than that of the system in this paper, which verifies the superiority of this system.

5. Conclusions
Based on the research and demonstration of the entire transformer temperature measurement system, this paper has completed the development of a fiber grating temperature measurement terminal based on the MSP430 single-chip microcomputer. The terminal instrumentizes the temperature measurement system, integrating functions such as light source, demodulation, calculation, display, and communication, and can also form a monitoring network with other equipment. The terminal can realize the dynamic monitoring of the temperature of the transformer's parts that are prone to heat, display the temperature information of its measuring points in real time, and upload the measured data to the upper computer in the control room to realize the remote measurement of the transformer, which is convenient for the power management personnel. Efficient management of various operating parameters improves the automation level of substations. The current transmission network is no longer only responsible for power distribution. With the gradual popularization of power optical cables, if better protection of the transmission network becomes the key direction of the next study, it will affect the data flow and power load in the transmission network. Monitoring is also the focus of the next step of research. In short, the transmission network will move towards a more intelligent development road.

References
[1] Gurevich V, Bridge K. Protecting High - Power Electrical Equipment from EMP. 2017,
10.1002/9781119271444:205-216.

[2] Zhan S. How to Build EQ System for Safety Classed Electrical Equipment Under the Modal of AE// International Confernece Pacific Basin Nuclear Conference. 2017, 23(1-3):24-26.

[3] Lu Y. China's Electrical Equipment Manufacturing in the Global Value Chain: A GVC Income Analysis Based on World Input-Output Database (WIOD). International Review of Economics & Finance, 2017, 52(NOV.):289-301.

[4] Wei, We, Jinpeng, et al. Graphene-Based Long-Period Fiber Grating Surface Plasmon Resonance Sensor for High-Sensitivity Gas Sensing. Sensors, 2016, 17(12):2.

[5] Kaili R , Liyong R, Jian L, et al. Online fabrication scheme of helical long-period fiber grating for liquid-level sensing. Applied Optics, 2016, 55(34):9675.

[6] Tuan, Guo. Fiber Grating-Assisted Surface Plasmon Resonance for Biochemical and Electrochemical Sensing. Journal of Lightwave Technology, 2017, 35(16):3323-3333.

[7] Chen D, Zhu Y, Zhao Z, et al. An intelligent remote control system for ECEI on EAST. Plasma Science and Technology, 2017, 19(008):49-53.

[8] Tapetado A , Diaz-Alvarez J, Miguelez H, et al. Fiber-optic Pyrometer for very Localized Temperature Measurements in Turning Process. IEEE Journal of Selected Topics in Quantum Electronics, 2016, PP (99):1-1.

[9] Yuntao, Yan, Chongqing, et al. Temperature characteristics of a BGO fiber-optic voltage transformer.. Applied optics, 2019, 58(28):7781-7788.