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Fiber Bragg Grating Temperature Measurement Combined with Infrared Flame Detector Applied to Highway Tunnel Fire Monitoring

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Abstract: There is no flame detection technology that could adapt to all kinds of tunnel fire monitoring alone. Fiber Bragg Grating temperature measurement technology has the advantage of stability and sensitivity to temperature. Three wavelength infrared flame detector can detect the flame which could not change the temperature significantly in a short period of time. In this article, we combine Fiber Bragg Grating temperature measurement with an infrared flame detector to monitor tunnel fire. The combination of line type and point type is more suitable for fire monitoring in highway tunnel.Ensure the effectiveness and stability of flame monitoring.It is an important safeguard to prevent and contain highway tunnel fire.

1. Highway Tunnel Fire Overview

The construction of highway tunnels is conducive to overcoming terrain obstacles such as mountains, and can effectively prevent natural disasters such as rolling rocks, mudslides, and avalanches on steep mountain slopes. It is also an effective means to preserve natural landscapes, protect the ecological environment, and save land. With the rapid construction of highways in high-speed development of mountainous areas in China, the proportion of highway tunnels is also increasing, especially the proportion of extra-long tunnels is also increasing. As a special structure of highways, due to limited space, complex terrain, and closed structure, the limited rescue space, and other characteristics, once a fire occurs, if it cannot be detected and dealt with in time, the consequences will be disastrous. Therefore, the design of the fire alarm system in the tunnel should be aimed at preventing problems before they occur, discovering them as soon as possible, and fighting them as soon as possible. How to give full play to the role of the fire alarm system in the tunnel and improve the safety of the system is a problem we must face and solve.

Because highway tunnels have the characteristics of long and narrow structure, small space, narrow roads, and poor ventilation conditions, once a fire occurs, a large amount of smoke generated by the combustion materials is difficult to be discharged in a short time, and the fire spreads quickly. Tunnel fires are generally composed of gasoline (acetone), alcohol, and wood according to the burning materials. For gasoline burning caused by vehicle fuel leakage or vehicle collision, the flame will develop in a jumping manner, and the flame spreads at the fastest speed. It will even cover the entire tunnel cross-section in a very short time, which is more harmful. Therefore, the flame detection in the tunnel is mainly aimed at such flames. Alcohol-based flames are mainly caused by the burning of flammable materials loaded on vehicles or overheating of equipment cables in tunnels. Its burning speed is relatively slow, which is basically the same as that of wood flames, and its development process is a sequential process. This kind of flame should be detected and prevented early, and the flame detection can be carried out by the method of multisensor fusion[1-2]. Taking the “8.27 Wenmaoliing Tunnel Fire Accident in Yongtai, Zhejiang Province” as an example, it was preliminarily identified that the fire exploded and caused the cargo to catch fire. The smoke made the passing vehicles unable to drive. Due to the first generation of thick smoke, there was no open flame, and only a single flame detection was used. The detection method of the fire alarm will cause the fire alarm time to lag and delay the rescue time. It can be seen that for the monitoring of smoke fires, it is necessary to introduce a system integrating fiber grating, temperature measurement, and flame detectors to ensure the safe operation of the tunnel.

2. Commonly used Highway Tunnel Fire Alarm Technology

The automatic fire detection technology of expressway tunnel has developed from the air copper tube temperature detection to the current popular optical fiber temperature detectors, infrared flame detectors, image flame detectors, etc. These automatic fire detection technologies have shown in different engineering applications. different detection effects [3].

2.1. Fiber Bragg Grating Thermal Fire Detection System

The basic principle of fiber grating sensing is to use the effective refractive index of the fiber grating and the sensitivity of the grating period to external parameters to convert the change of the external parameter into the shift of the Bragg wavelength, and realize the detection of the center wavelength of the grating reflection. Measurement. For the broadband light incident on the fiber grating, only the light of the wavelength that meets certain conditions can be reflected back, and the rest of the light is transmitted [4-5]. The fiber grating detection cable is composed of gratings with different Bragg wavelengths in series. Based on the wavelength division multiplexing technology of optical fibers, the signals between different gratings will not crosstalk each other. The light source used is a common broadband light source rather than an expensive and easily lost laser light source. Moreover, the wavelength signal is more stable than the intensity signal and will not be changed by the attenuation or insertion loss of the light source, which also provides convenience for the signal demodulation system, makes the response speed faster, and buys time for tunnel disaster prevention and relief.

The main parameter detected by the fiber grating fire monitoring system is temperature. The system measures the temperature according to the change of the Bragg wavelength of the fiber grating and gives early warning and alarm signals according to the preset judgment conditions. The alarm basis includes differential temperature alarms and fixed temperature alarms. When the system monitors the temperature of a certain area and the temperature rise rate exceeds the set value for several consecutive seconds, a differential temperature alarm signal will be generated; when the system monitors that the temperature value of a certain area exceeds the fixed temperature setting when the value is set, a constant temperature alarm signal will be generated. The system can use the high-temperature smoke alarm generated in the early stage of the fire. At this time, the high-temperature smoke will quickly rise to the top of the tunnel. The fiber grating installed on the top of the tunnel senses the drastic change in temperature and responds in time.

In engineering installation, fiber grating products are easy and convenient, do not need to be energized on site, and the products are intrinsically safe and explosion-proof. The temperature signal of the tunnel site is transmitted to the signal processor of the tunnel substation through the transmission optical cable. The signal processor inputs the alarm and fault signals to the fire alarm controller, and the temperature signal is uploaded to the computer of the monitoring center through the network port. The DC uninterruptible power supply (UPS) supplies power to the signal processor, and the layout of the engineering equipment is shown in Figure 1:

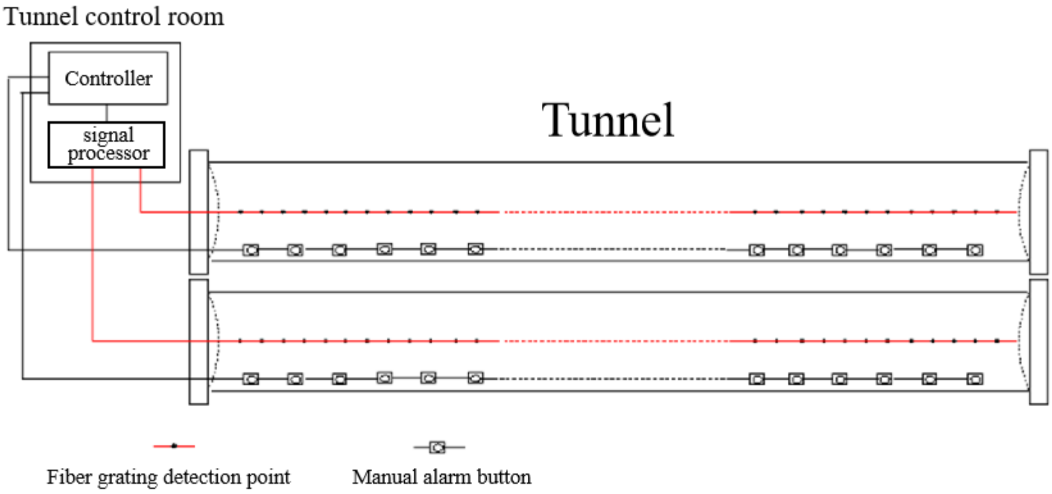

Figure 1: Schematic diagram of engineering equipment layout of fiber Bragg grating thermal fire detection system

2.2. Infrared Flame Detector

Infrared flame detectors conduct fire discrimination based on the spectral absorption peak characteristics of hydrocarbon combustion products [6-7]. In addition to requiring high sensitivity to flames, flame detectors must also be able to identify and reduce the influence of nonfire background light. The basic principles of dual-band infrared flame detector and triple-band infrared flame detector are the same, but in dual-band infrared flame detector, two pyroelectric sensing elements are used as infrared sensors, and through two signal processing channels, it responds to the radiative changes of the flame light signal and the background light signal in two bands in the infrared spectral region, respectively. The three-band infrared flame detector has three infrared sensors, which can respond to the radiation changes of the flame light signal and the background light signal in the three bands of the infrared spectral region. Compared with dual-band infrared flame detectors, three-band infrared flame detectors have higher sensitivity, so it is more reliable to use three-band infrared flame detectors in tunnel fire fighting.

Considering the influence of sunlight and ambient light, the three-band infrared flame detector actually only selects a few narrower infrared spectral bands, using three bands of 4.4um, 3.8um, and 5.0um, which can simultaneously exclude high-temperature objects (such as artificial heat sources, sunlight, arc welding, etc.) and low temperature objects (such as artificial light sources, car headlights, etc.).

The detector uses two three-wavelength infrared sensing windows on the left and right for detection. The working principles of the left and right detection windows are the same. Three optical infrared narrow-band pyroelectric sensors are used to identify the flame situation and have the highest sensitivity to CO_2 emission spectrum (4.4um). Only when the data is consistent with the predefined flame infrared spectrum model, the detector outputs an alarm. This ensures that the detector can achieve maximum flame identification with the fastest response time and with absolutely no false alarms.

By applying three-wavelength infrared technology and high-sensitivity narrow-band sensors, it not only enhances the sensitivity, but also expands the detection range. The large detection range means that the number of detectors used in the entire area to be detected is reduced, which can greatly save equipment and installation costs. The detection angle of view can reach 180°, and the linear detection distance of the horizontal center can reach 25m.

The infrared flame detector has a double fan-shaped cone area with a detection field of view of 180°, and the straight-line distance between the horizontal centers can reach 25 meters on the left and right. Figure 2 shows the distribution of the detection field of view of the detector, and the double sector area is the effective detection area of the detector.

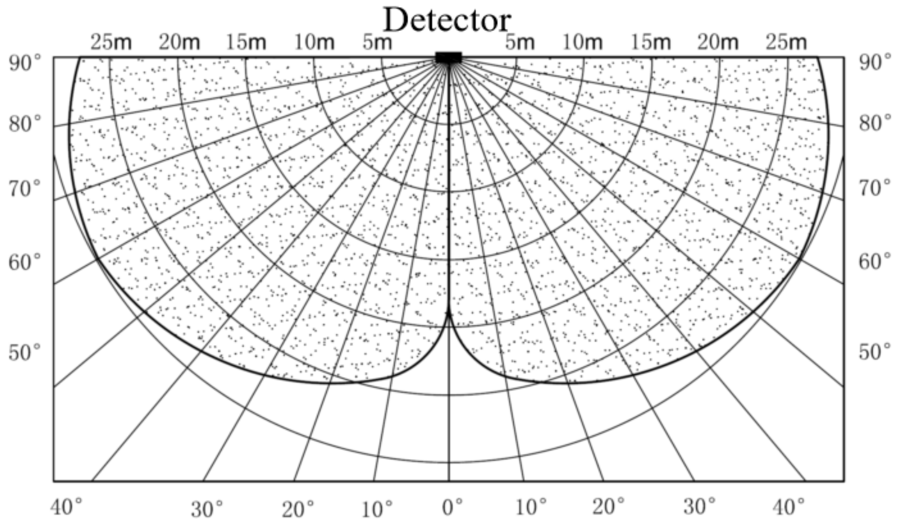

Figure 2: Schematic diagram of the detection range of the infrared flame detector

2.3. Image Fire Detector

Image fire detection is characterized by a large amount of information, visualization, and the availability of CCTV monitoring systems in tunnels. Through the image processing algorithm, the judgment is made by analyzing the physical characteristics of the fire in the video. For example, parameters such as flame color, texture, time-varying brightness, flickering frequency, and edge variation are analyzed as fire detection criteria. However, since it also introduces unnecessary interference when using video technology to detect flames, the following problems need to be solved by using video to detect flames[8-10].

1) Brightness conditions: day and night, unnatural light, reflections of light, shadows, front and rear lights of the vehicle.

2) Image quality: camera resolution, poor camera contrast, poor signal transmission, dirty lens, human damage.

3) Environmental complexity: moving objects, different sizes and speeds of moving objects, and car exhaust.

4) Processing performance: real-time detection, processing speed, and disk capacity.

5) Good configuration parameters: Use the background image and the collected image sequence to extract the flame candidate area and the smoke candidate area.

In the tunnel, the fire must be accompanied by smoke, and sometimes the smoke will seriously interfere with the detection of flame color and dynamic frequency. In addition, ordinary hemispheres, bolts, and gimbal are not supported in high temperature environments. The working temperature of ordinary camera is about -20℃~60℃. This temperature range covers the common working environment of cameras. However, when a tunnel fire occurs, the ambient temperature can instantly rise to 800℃, far exceeding the upper limit of the working temperature of the camera. The monitoring system fails. Due to multiple interference factors and complex algorithms, video probes need power supply and other factors, the video analysis system has a high false alarm rate and failure risk[11], and its technical maturity is not high, so there are few market use cases.

The image fire detection algorithm is complex and susceptible to interference, and the video probe is not resistant to high temperature. For the fiber grating temperature measurement system, the optical fiber is made of quartz material, and the optical fiber is used as both a detector and a transmission medium. The detection optical cable part is not charged and does not need power supply, and is resistant to high temperature and corrosion, which essentially makes up for the video probe’ s shortcoming.

2.4. Technology Comparison

Table 1: Comparison table of common highway tunnel fire alarm technologies

		fiber grating	Infrared flame detector	Image flame detector
Characteristics	Detection principle	wavelength change	spectral change	image change
	Probe Type	Ambient temperature rise	flame spectrum	flame image
	Detection conditions	Burn more heat	With open flame	With open flame
	environmental impact	Affected by wind speed, Not affected by pollutants	not affected by wind speed, Pollutants have less impact	not affected by wind speed, Pollutants have a big impact
	Response time	Less than fast	fast	fast
	coverage	A single meter can cover several kilometers	One every 50 meters	One every 50 meters The detection distance of the optical lens is inversely proportional to the angle of view
Product Model	Explosion-proof grade	Intrinsically safe	Explosion proof optional	Explosion proof optional
	Protection class	Field detector IP68	Usually IP65 or IP66	Below IP65
	System composition	Simple, lay the detection cable on site, and place the host in the station	More complicated, there are integrated panels and power panels on site, and communication remote transmission equipment is required in the station	Complex, multiple cables, power supply equipment, communication facilities, host, video equipment and other equipment in the station
	System networking	The sensing signal is transmitted directly through the optical fiber, which is simple and convenient	RS485 for short distance, optical fiber for long distance	Difficulty in remote transmission of video signals
	Product Consistency	Good, all items are of the same type	According to different project requirements Choose a different product	Select according to resolution, explosion-proof type and IP level; Different detection ranges also have different models. Different detection objects should be equipped with different accessories, such as searchlights, auxiliary temperature sensors, etc.

Based on the above factors, the comparison of various fire alarm products is shown in Table 1 from the perspectives of product characteristics, product selection, on-site implementation, and postmaintenance.

3. Tunnel Fire Alarm System Combining Fiber Grating Temperature Measurement and Flame Detector

Referring to the Design Specification for Automatic Fire Alarm System[12], it is recommended to use fiber grating temperature-sensing fire detector products within 2km and two-lane tunnels; over 2km or 3-lane tunnels and key traffic tunnel projects (urban road tunnels) Tunnel, underwater tunnel) It is recommended to use fiber grating and other fire alarm systems in combination.

The flame detection of highway tunnels should combine the advantages of fiber grating temperature measurement systems and flame detectors, especially in extra-long tunnels. flame to ensure the accuracy of the alarm and fewer false alarms. The monitoring process is shown in Figure 3.

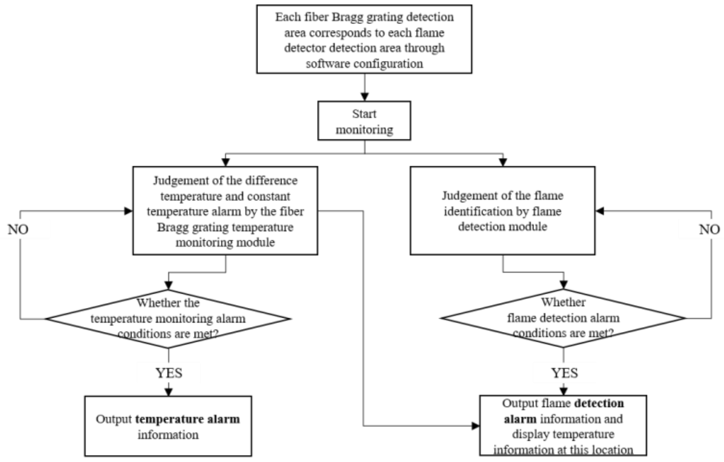

Figure 3: Tunnel fire alarm system monitoring process

The temperature-sensing fire alarm detector has the characteristics of strong antiinterference, high resolution, high precision, and good stability, but the influence of the natural wind in the tunnel will cause drift and deviation of the monitoring results; the infrared flame detector is not affected by wind speed and temperature it can quickly respond to the fire, but if there are obstacles in the fire scene, it will affect the judgment of the flame. Combining the fiber grating temperature measurement technology with the infrared flame detector technology for judgment, the two methods complement each other and can achieve a good tunnel fire monitoring effect.

4. Conclusions

The timely monitoring of highway tunnel flames is of great significance for the prevention of tunnel fires. The fiber grating temperature measurement system has the advantages of good stability and sensitive temperature response; the infrared flame detector can timely detect the flame that will not cause a sudden temperature change in a short time. As a point-type alarm system, the infrared flame detector is used in conjunction with the distributed fiber grating thermal fire alarm system. The combination of line type and point type is more suitable for highway tunnel fire monitoring. It can achieve complementary features and superposition of advantages. Fast and accurate detection of highway tunnel fires, providing accurate information for rescue and taking measures, effectively ensuring the safety of people's lives and property, and providing safe and reliable travel services for drivers and passengers.

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