Analysis of solar interference simulation test for flame detectors

Chen Zhong\textsuperscript{1,*}, Shen Liu\textsuperscript{1}, Yu Shao\textsuperscript{1}, and Xiaoxiao Xu\textsuperscript{1}

\textsuperscript{1}Shenyang Fire Science and Technology Research Institute of MEM, Shenyang, Liaoning, 110034, China

*Corresponding author: zhongchen@efire.cn

Abstract. The light interference is an important reason for the false alarm or blindness of the flame detectors, and the effect of sunlight interference is particularly significant. In order to meet the requirements for the evaluation of the anti-sunlight interference performance of the flame detector, it is necessary to classify the solar interference severity according to the light climate data. On this basis, the solar interference simulation equipment and test method with quantitative test are designed. Through tests under different seasons, times and light conditions, the reliability and effectiveness of the test equipment and test methods are verified, the measurement uncertainty is calculated. Test results provide technical support for the standardization of sunlight interference test.

1. Introduction

In the current relevant international or national standards, the light interference test of flame detectors is mainly simulated by indoor artificial lighting sources such as incandescent lamps and fluorescent lamps\cite{1,3}. However, with the widespread application of flame detectors in open or semi-open places such as tunnels, petrochemical plants, vehicles and ships, the interference effects of automobile headlights and sunlight are receiving more and more attention\cite{3,4}.

Because the radiation intensity and spectral characteristics of artificial light source are quite different from that of sunlight, it is impossible to objectively evaluate the response performance of flame detectors in real sunlight interference environment only by artificial light source. Therefore, it is necessary to analyze the solar interference of flame detectors installed in open spaces and determine the solar interference severity. On this basis, standardized solar interference simulation equipment with irradiance and irradiation direction control function is necessary for quantitative simulation of solar interference source. At the same time, for the ability of sunlight collection, it is necessary to conduct a comprehensive feasibility analysis, so as to ensure the operability of the solar interference test method and meet the requirements of measurement uncertainty.

In this paper, through the test and analysis of response characteristics with typical flame detector under the conditions of methane test fire, halogen lamp and sunlight, the importance of sunlight interference test is determined. According to the solar interference severity level established based on multi area light climate data, the quantitative simulation test equipment and method of solar interference are designed. By multi-group test in different seasons, times and light conditions, the validity of the test method is verified and the uncertainty of measurement is then calculated.
2. Light interference response of the detector

2.1. Light interference test

In order to test the effect of common light interference on flame detectors, pyroelectric infrared components sensitive to infrared radiation of 5.0μm, 4.5μm and 3.8μm wavelengths were used to construct a test device, as shown in Fig. 1.

According to the arrangement shown in Fig. 2, the flame detector was tested for the response of the methane test fire (Fig. 2 (a)), halogen lamp (Fig. 2 (b)) and sunlight (Fig. 2 (c)).

In the test of the methane test fire, the test device is installed on the optical track of the optical bench, and the position of the test device is adjusted along the optical axis, so that the distance $D$ from the flame to the sensitive element is 1.5m. The fire source uses methane gas with a purity of 99.9% to burn, the flame height is about 5cm, and the chopping frequency of the modulator is 10 times/s.

In the halogen lamp test, keeping the sensitive element of the test device and the light source on the same optical axis, and the distance $D$ is set to 1.5m, and the chopping frequency of the modulator is 10 times/s.

In the sunlight test, keep the optical axis of the test device consistent with the direction of sunlight. The solar illuminance is about 50,000lx. At a distance $D$ of 1.5m from the sensitive element of the test device, the modulator is used to chop at a frequency of 1 time/s.

![Detector with 5.0μm, 4.5μm and 3.8μm pyroelectric infrared sensitive element.](image)

![Methane test fire response test](image)

![Halogen light response test](image)
2.2. Analysis of test results

The response of the test device to methane test fire, halogen lamp and solar radiation is shown in Fig. 3 (a) (b) (c) respectively. Among them, red represents 3.8μm wavelength response, green represents 4.5μm wavelength response, and purple represents 5.0μm wavelength response.
(c) Sunlight response

Fig. 3. Response of flame detector to common light radiation.

From the test results, the 4.5μm wavelength sensitive element has a more obvious response to the methane test flame than that of 3.8μm and 5.0μm. All of the three sensitive elements have no obvious response to the halogen lamp radiation, but all response to solar radiation is strong, even some data shows distorted.

Therefore, the interference effect of sunlight on flame detectors is more significant than that of halogen lamps. For single infrared flame detectors using 4.5μm, it is almost inevitable to produce false alarms under sunlight interference conditions. The inspection of the flame detector's anti-sunlight interference performance is very important for the reliability and stability of the detector.

3. Experimental design of sunlight interference

3.1. Test parameters and severity level

For flame detectors used in open or semi-open spaces, it is generally required that the monitoring angle of the detector be horizontal or obliquely downward, and be equipped with sunshades to avoid direct sunlight. Therefore, the interference effect of the scattered radiation of sunlight and the direct radiation of the vertical plane on the flame detector should be mainly considered.

From the data of China Meteorological Data Network (CMDN), we can obtain the daily maximum irradiance of total radiation $E_m$ and the daily maximum irradiance of vertical radiation $E_v$. The daily maximum irradiance of scattered radiation $E_s$ can only be estimated by the solar radiation model\cite{5-7}.

According to the light climate data of Shenyang, Shanghai, Guangzhou and Yuzhong in China from 2017 to 2019, through the data analysis of vertical direct radiation and scattered radiation, the severity level of the solar interference test for flame detectors can be classified as shown in Table 1:

| Severity level | Irradiance (W/m²) | Illumination (lx) | Application |
|----------------|-------------------|------------------|-------------|
| 1              | 70                | 8000             | Minimum requirements for environments where there may be solar radiation interference |
| 2              | 300               | 35000            | Anti-interference requirements for non-direct solar radiation |
### Minimum requirements for environments where direct solar radiation may be present

|   |   |   |
|---|---|---|
| 3 | 500 | 60000 |

|   |   |   |
|---|---|---|
| 4 | 1000 | 110000 |

### Requirements for anti-interference of vertical direct solar radiation

#### 3.2. Test equipment and methods

In order to simulate some or all of the severity levels of solar interference in Table 1, and verify the anti-sunlight interference performance of flame detectors, the strategy of sunlight tube natural lighting combined with darkroom light rail dimming is adopted\(^8\), as shown in Fig. 4.

The structure and function of the solar interference simulation equipment is shown in Fig. 4 (a), where: 1. Transparent cover, 2. Light tube, 3. Tube holder, 4. Optical dark box, 5. Optical slide rail, 6. Sunlight input direction, 7. Optical axis, 8. Sliding seat, 9. Height-adjustable sample holder, 10. Flame detector, 11. The plane of sensitive element and illuminance meter, 12. Sliding seat position adjustment direction, 13. Optical dark box support.

![Structure function diagram](image)

![Equipment physical panorama](image)

![Internal installation drawing](image)

Fig. 4. Solar interference simulation equipment.
The structure of solar interference simulation equipment is mainly divided into two parts:

- Sunlight collection module: through the transparent cover, the sunlight can be injected into the light tube, and through reflections on the metal reflective surface of the inner wall, the sunlight can be emitted along the horizontal direction.

- Solar interference test module: the sunlight output from the sunlight collection module is introduced into the optical dark box, and the distance between the flame detector and the incident sunlight along the optical axis is adjusted through the sliding rail, sliding seat and sample holder. Through the illuminance meter installed near the sensitive element of the sample, the sunlight illuminance at each sliding position is measured until it reaches the specific illuminance required by the test.

4. Results of solar interference test

4.1. Test data analysis

Under different seasons, times and sunlight conditions, the reliability and applicability of the solar interference simulation equipment is examined by measuring the illuminance at different distances in the direction of the optical axis. The test location is Shenyang, China, with longitude of 123.38E and latitude of 41.8N. Four trials of illuminance data points and the fitting curves are shown in Fig. 5.

Through data analysis, the sunlight collection is less affected by seasonal factors. At noon in summer (06/17/20), winter (02/22/21) and spring (03/19/21), the maximum of about 23000lx imported sunlight can be collected, and it can reach severity level 1 (8000lx) at about 0.3m optical path.

Whether the transparent cover of the equipment is in shadow range has a great impact on the sunlight collection effect, as shown in Fig. 5 for the data marked in red and blue.

4.2. Measurement uncertainty

Type A evaluation defined in ISO/IEC Guide 98-3: 2008 Uncertainty of measurement-Part 3: Guide to the expression of uncertainty in measurement (GUM: 1995) is used for estimating the standard uncertainty of the measurements as shown in Formula 1[9].

\[
s_p(x_i) = \sqrt{\frac{1}{m(n-1)} \sum_{i=1}^{m} \sum_{j=1}^{n} (x_{ij} - \bar{x}_i)^2}
\]

where \( s_p(x_i) \) indicates the combined standard deviation of the \( k \)th trial, \( i (i=1, 2, 3, \ldots, m) \) indicates the number of test groups, \( j (j=1, 2, 3, \ldots, n) \) indicates the number of measurements in each test group, \( x_{ij} \) indicates the \( j \)th measurement of the \( i \)th test group and the average in the \( i \)th group is \( \bar{x}_i \). The data statistics and measurement uncertainty of each trial are shown in Table 2.
Table 2. Data statistics and measurement uncertainty in solar interference simulation test.

| Trials | 1               | 2               | 3               | 4               |
|--------|-----------------|-----------------|-----------------|-----------------|
| Test time | 06/17/20 13:30 | 06/17/20 13:50 | 02/22/21 10:50 | 03/19/21 12:40 |
| Lighting conditions | shining | shadowing | shining | shining |
| Outdoor horizontal illuminance (lx) | 69333 | 17326 | 65850 | 67060 |
| Outdoor vertical illumination (lx) | 43256 | 7563 | 41127 | 35217 |
| Output illuminance in equipment (lx) | 22951 | 7180 | 21900 | 22704 |
| Measurement uncertainty | 106.94 | 41.98 | 204.51 | — |

5. Conclusion
Compared with halogen light, the interference effect of sunlight on flame detectors is more obvious. The flame detector's anti-sunlight interference performance is very important to ensure the reliability of the flame detector's performance. Therefore, according to the light climate data of different regions, on the basis of establishing the evaluation standard and severity level of anti-sunlight interference performance of flame detector, the solar interference simulation tests under different seasons, times and light conditions are tested. The feasibility and effectiveness of the test equipment and methods are verified through data analysis.

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