

## Study on Signal Detection of the Instantaneous Infrared Target Based on Finite Element Analysis

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**Abstract:** This paper presented a novel method to detect the signal of the instantaneous infrared target based on the Finite Element Analysis (FEA). The radiation energy produced by flame infrared target was divided to finite element section. Studied the distribution of the unit area energy of flame in the detection system and the calculation method of flame radiation obtained by the photosensitive surface of infrared detector in the optical field, we set up a target detection model based on FEA for infrared targets and deduced a calculation formula of the output signal of the infrared flame detection system. Furthermore, the paper analyzed the factors of the influence detection effect both of the environmental factors and the angle of incidence optical system, and simulated the relationship between all parameters of the established model and the characteristics of the object detected. The results of experimental data was consistent with the simulation result verified the correctness of the infrared target detection model established. *Copyright © 2013 IFSA.*

**Keywords:** Infrared target, Infrared radiation, Detection model, FEA, Sensitivity.

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### 1. Introduction

In the petroleum and chemical industry, flammable and explosive goods are usually stored, processed and transported in the outdoor environment. Most of the inflammable and explosive goods will produce a larger quantity of heat, in an accident with thermal radiation energy, reaction speed is transient. For this type of dangerous goods accident detection, so need detection device has the thermal response characteristics of high sensitivity and timely response. In this kind of place, Infrared flame detection system is the first choice for fire detection devices since it has the advantages of short response time and long detection distance.

For infrared detection system of detecting distance and surveillance of wide field of view, how to obtain the transient infrared signals is the key to design the infrared flame detection system. At

present, the infrared target detection generally uses the following two methods. The first is to use IR camera to capture the target, by recognition and analyze infrared images to detect the flame. This method is close to the human visual habits and need to process the infrared image. The second method is to use infrared sensors to identify the thermal radiation of infrared target. The infrared detector is more frequently used in the radiation detection of hydrocarbon compounds combustion. This paper adopts the method of finite element analysis, transient flame is decomposed into a finite number of infrared target sources, as an object, established on the basis of the infrared target source of target detection model, and the calculating formula of the output signal of the infrared flame detection system is deduced. Furthermore, the paper analyzes the influence effect for the detection signal of external environment, such as the sun, the earth radiation,

angle of incidence optical system. Through simulation and practical test for the model established, we verify the correctness and feasibility of the model established. Also, this paper provides a new method of calculation and analysis for the transient flame signal detection using infrared detector under the condition of long distance.

The following content of paper is organized as follows: Section 2 presents the model of IR target detection based on FEA. Section 3 analyzes environmental effects for the detection performance. Section 4 is simulation and Section 5 test. Finally, section 6 gives the conclusions.

## 2. The Model of Infrared Target Detection Based on FEA

### 2.1. The Infrared Target Detection Range

Whether can detect infrared target, the commonly used method is based on the target radiation power produced in the detector response based on whether meet the requirements of signal to noise ratio [1], as shown in equation (1).

$$R = \left[ \frac{\pi \cdot \tau_a \cdot \tau_0 \cdot I \cdot D^* \cdot D^2}{4\sqrt{A_d \cdot \Delta f} \cdot (V_S/V_N)} \right]^{\frac{1}{2}}, \quad (1)$$

where  $R$  is the distance from the transient flame to infrared detector.  $\tau_a$  is atmospheric transmittance,  $\tau_0$  is transmittance of optical system,  $I$  is the target radiation intensity,  $D^*$  is the detection rate for detector,  $D$  is aperture optical system,  $A_d$  is detector photosensitive surface area,  $\Delta f$  is the bandwidth of the system,  $V_S/V_N$  is the minimum requirement for signal processing SNR.

### 2.2. Flame Thermal Radiation Energy Obtained by Infrared Detector

Assume that transient flame within the space and distribution in a rectangle area which long is  $a'$ , wide is  $b'$  and high is  $c'$ . Due to the transient flame distribution in space and present irregular shape, Detector collection transient flame from the light of a particular direction. Assume that the energy distribution by fire centers on the optical system's optical axis. On the optical axis direction, the light energy of positive side of the optical system is larger than deviation of the surface, so only to select half of the cuboid area (length is  $a'$ , width is  $b'$  and height is  $c'/2$  respectively) which close to the optical system [2].

Using finite element method to decompose transient flame in this half of the rectangle area and

divided into a number of flake finite element. Transient flame finally presents an image in the plane where the detector is on through the optical system, the image's shape is corresponding to the largest image in flake finite elements. At the same time, the largest finite element in a number of flake finite element also carry most of the energy, So we choose the largest plate finite element as the research object. Flake plate finite within the cuboid area for long is  $a$ , for width is  $b$ , as shown in Fig. 1.

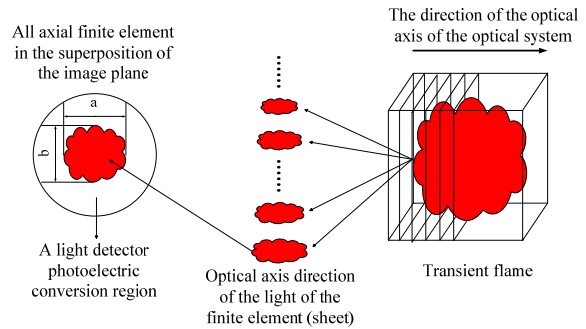


Fig. 1. The finite element decomposition of transient flame in the optical axis.

Using the finite element method for further decompose the selected flake finite element's rectangular area. Divided into the finite element which area of micro element is  $S_{(i,j)}$ ,  $i$  column  $j$  line, as shown in Fig. 2. Within the selected rectangle, there are covered completely and incompletely micro elements. For the former we can make use of  $a/i$  and  $a/j$  as two side length to calculate the area of micro element, for the latter we can get the area through the finite element partition computation and accumulation to the irregular coverage area of the micro element.

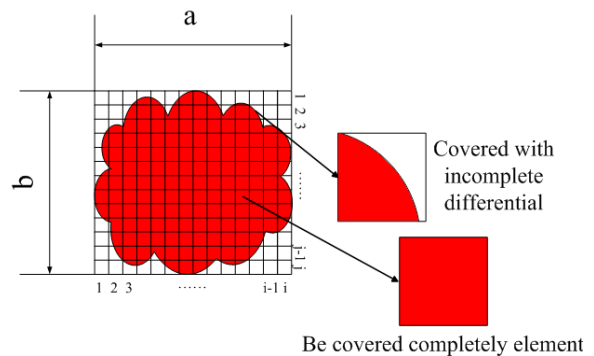


Fig. 2. The finite element division of transient flame irregular imaging in the image plane.

The transient flame temperature is much higher than absolute zero, therefore the target surface will radiate energy into space [3]. In the above selected rectangular area, the infrared radiation energy of the

transient flame received by the micro element area. The energy can be calculated by the formula (2):

$$P_{(i,j)} = \varepsilon \cdot \sigma \cdot T^4(t) \cdot S_{(i,j)}, \quad (2)$$

where  $P_{(i,j)}$  is the infrared radiation energy of the transient flame received by the micro element area;  $\varepsilon$  is the emissivity of target surface;  $\sigma = 5.67 \times 10^{-8} (\text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-4})$  is the Stephen-Boltzmann constant;  $T(t)$  is the transient flame temperature in  $t$  time.

According to image relationship, assume that the optical lens focal length is  $f$  and we can get the calculation formula of the light surface element which is get through infrared detector correspond:

$$P'_{(i,j)} = \frac{\varepsilon \cdot \sigma \cdot T^4(t) \cdot S_{(i,j)} \cdot f}{\varepsilon \cdot \sigma \cdot T^4(t) \cdot S_{(i,j)} - f}. \quad (3)$$

Using the formula (3) can calculate thermal radiation energy of the flame surface in the infrared detector photosensitive surface. The formula indicates that the thermal radiation energy of the flame surface gained by infrared detector increase when the optical system focal length increase. At the same time, it means the relative detection distance of flame infrared detection system increase, and it can effectively increase the sensitivity of the detection system for the remote measured target [4].

Due to calculate the output expressions of fire infrared detection system, we need to establish the relationship between thermal radiation energy and infrared detector photosensitive surface area. Therefore, it is necessary to calculate the radiation intensity [5]. Radiation intensity refers to the ratio between the radiation exposure to the bin and the area, as the following formula:

$$I = P' / S, \quad (4)$$

where  $P'$  is the radiation energy of selected rectangular area. Put (3) into (4) we can get the following formula:

$$I = \frac{\varepsilon \cdot \sigma \cdot T^4(t) \cdot \sum_{n=1}^i \sum_{m=1}^j S_{(i,j)} \cdot f}{a \cdot b \cdot (\varepsilon \cdot \sigma \cdot T^4(t) \cdot \sum_{n=1}^i \sum_{m=1}^j S_{(i,j)} - f)}, \quad (5)$$

Get the total radiation energy of infrared detector photosensitive surface by using the method of accumulate each surface's radiation energy, and then use the formula (4) transformation relations, obtain the calculation formula of infrared detector photosensitive surface's total radiation intensity. We can obtain the following conclusions from the calculation formula: Under the certain premise in

flame thermal radiation energy, increasing the area of the infrared detector photosensitive surface would reduce the total radiation intensity. So in the infrared detector photosensitive surface, thermal radiation intensity which is detected by the infrared detector is the largest when the image space flame radiation area is equal to the photosensitive surface area. As the image space flame radiation area is less than the photosensitive surface area, infrared detector can detect the total radiation energy. However, with the increase of the photosensitive area, the radiation intensity decreased, and the decreased sensitivity of infrared detector. When the image space flame radiation area is greater than the photosensitive surface area, part of flame's thermal radiation energy will not detected by infrared detector, so the flame radiation energy is lost and it will make the detection sensitivity of infrared detector decline. Therefore, under the premise of the image space flame radiation area is equal to or greater than the, try the best to make the image space flame radiation area is close to photosensitive surface area in order to improve the sensitivity of infrared detector effectively.

### 2.3. The Luminous Flux of Flame Radiation to the Detector

The change of the luminous flux when light through the optical system will directly affect the infrared detector to obtain flame thermal radiation [6]. At the same time, we can deduce the SNR of flame infrared detection system through the calculation of luminous flux of background radiation and infrared target radiation [7]. The SNR of the system is an important parameter for the analysis of the sensitivity of infrared detector [8]. Assume that the intensity of the radiation background is  $I'_B$ ; the viewing angle when the transient flame is  $\theta$ ; so the radiation background area get by the detector is:

$$S_\theta = \theta \cdot R^2, \quad (6)$$

The corresponding background radiation intensity of infrared system is as follows:

$$I_B = I'_B \cdot S_B = I'_B \cdot \theta \cdot R^2, \quad (7)$$

Assume that the transient flame is infinitely far away from the detector, Background radiation can be considered as a point source in the aspect of imaging [9], if aperture of the optical lens is  $D$ , transmittance is  $\tau_0$ , The background radiation flux get by the infrared detector can be calculated by the formula (8):

$$\Phi_B = \tau_0 \cdot I_B \cdot \frac{\pi \cdot D^2}{4R^2}, \quad (8)$$

Assuming that transient flame radiation intensity is  $I'_m$ ; the transmittance when the light radiate in the atmosphere is  $\tau_a$ ; so when there is  $R$  distance from the transient flame, Infrared detector receives the radiation flux is:

$$\Phi_m = \tau_a \cdot \tau_0 \cdot I'_m \cdot \frac{\pi \cdot D^2}{4R^2}, \quad (9)$$

So when the system's background noise is greater than the noise of the detector, the SNR of the infrared detector is:

$$V_s/V_N = \frac{\Phi_m}{\Phi_B} = \tau_a \cdot \frac{I'_m}{\theta \cdot R^2 \cdot I'_B}, \quad (10)$$

Therefore, under the certain radiation intensity of target signal of detection and background radiation intensity, and in the case of a target is detected as a point source targets, we can obtain that:  $I'_m/(\theta \cdot I'_B) = C$  is a constant. The SNR  $V_s/V_N$  of infrared detector as follows:

$$V_s/V_N = C \frac{\tau_a}{R^2}, \quad (11)$$

Analyze the formula (11), we can obtain that the SNR of the infrared detector is associated with the detection range of fire detection system under the certain premise in atmospheric transmittance [10], increasing the detection distance, would rapidly reduces the SNR of the infrared detector [11], and it will make the sensitivity of Infrared detector decline at the same time.

According to a series of derivation above, we can get the flame radiation intensity and the calculation formula of SNR of infrared detector by using the infrared detector photosensitive surface. We can derive the actual area of the flame when combined with the expression of infrared detector's detection distance, and get the calculation formula of infrared detector output signal eventually. Put (5), (11) into (1) respectively, we can obtain the detected transient fire finite element area  $S_0$  when the infrared detector parameters are identified:

$$S_0 = \sum_{n=1}^i \sum_{m=1}^j S_{(i,j)} = \frac{f}{\varepsilon \cdot \sigma \cdot T^4(t) \cdot \left(1 - \frac{\pi \cdot \tau_0 \cdot D^* \cdot D^2 \cdot f}{4C \cdot a \cdot b \cdot \sqrt{A_d \cdot \Delta f}}\right)}, \quad (12)$$

The infrared thermal radiation energy radiated by all the area in the selected rectangle flake finite element and we can deduced the energy  $P_0$  by (2) and (12):

$$P_0 = \frac{f}{1 - \frac{\pi \cdot \tau_0 \cdot D^* \cdot D^2 \cdot f}{4C \cdot a \cdot b \cdot \sqrt{A_d \cdot \Delta f}}}, \quad (13)$$

Infrared detector response rate is the ratio of output voltage and the input power of the infrared radiation:

$$\xi = V_s/P_0, \quad (14)$$

where  $\xi$  is the response rate;  $V_s$  is the output voltage;  $P_0$  is the radiation power. Put (13) into (14) we can get the calculation formula for the detector output voltage:

$$V_s = \frac{\xi \cdot f}{1 - \frac{\pi \cdot \tau_0 \cdot D^* \cdot D^2 \cdot f}{4C \cdot a \cdot b \cdot \sqrt{A_d \cdot \Delta f}}}, \quad (15)$$

From equation (15), we can conclude that infrared detector response rate, detection rate and the aperture and the transmittance of optical system increases, with increasing of the infrared detector output voltage. We can improve the sensitivity of infrared detector effectively under the premise of flame radiation is unchanged. Assume that the set threshold voltage is  $V_0$ , noise voltage is  $V_N$ , when the detector output voltage is  $|V_s - V_N| \geq V_0$ , we think that infrared detector can detect the transient fire signal.

### 3. The Environmental Effects of Detection Performance

#### 3.1. The Influence of the Sunlight

In an open environment, solar radiation is universal, solar direct radiation has a strong effect on the thermal radiation of flame signal [12]. In the infrared detection to flame signal, solar direct radiation energy can produce interference on the sensitivity of infrared detector, thus it is necessary to analyze the solar direct radiation effects on the fire [13]. Sun is hot sphere which radius is  $6.960 \times 10^5$  km and blackbody spectrum distribution approximation 5900 K. Due to the distance from the sun to the earth is largely greater than the radius of the earth, and the sun light in the space can be thought as radiation uniform parallel light, so the solar direct radiation energy  $P'_{(i,j)}$  absorbed by the number of  $(i, j)$  micro element in flake finite element is:

$$P'_{(i,j)} = \varepsilon_s \cdot E_s \cdot S_{(i,j)} \cdot F_{s,(i,j)}, \quad (16)$$

where  $\varepsilon_s$  is the absorption rate of target surface to the solar radiation;  $E_s$  is the sun radiation constant and its value is  $1353 \text{ W/m}^2$ ;  $F_{s,(i,j)}$  is the angle coefficient of the surface of micro element to the sun direct illuminate. Therefore, the main factors affecting the sun direct radiation is incident angle of sunlight, solar direct radiation energy changes with the change of solar radiation angle coefficient in one day. So as far as possible to reduce the sunlight incident angle coefficient to improve the sensitivity of infrared detector.

### 3.2. The Influence of Ground Radiation

Transient flame not only receives solar direct radiation, but also affected by the received surface radiation. Ground radiation can be divided into the solar radiation reflected by the earth and infrared radiation of the earth and its atmosphere system. The former can be regarded as indirect solar radiation. The latter is the heat radiation is produced by itself when the earth absorbs solar radiation energy [14]. Calculate the above-mentioned radiation energy is important, because it will affect the sensitivity of infrared detector when radiation energy effect on the flame signal.

The reflection of the earth to the sun radiation can be considered to be the surface evenly diffuse reflection [15], thus when calculating the reflection of the earth to the sun radiation, we can deal with the earth as a secondary light source. So the ground radiation energy  $P^*_{(i,j)}$  absorbed by the number of  $(i, j)$  surface element in flake finite element is:

$$P^*_{(i,j)} = \varepsilon_r \cdot E_s \cdot \rho \cdot F_{se,(i,j)}, \quad (17)$$

where  $\varepsilon_r$  is the target surface absorption rate of the earth reflection to solar radiation;  $\rho$  is the earth's albedo;  $F_{se,(i,j)}$  is the angle coefficient of the surface of micro element to the ground radiation.

Infrared radiation of the earth and its atmosphere system mainly comes from the earth to absorb that part of the solar radiation energy that is covered by the earth's surface temperature and cloud cover, according to the meteorological satellite data acquired from every year, earth radiant existence of years on average is  $237 \pm 7 \text{ W/m}^2$ , the blackbody spectrum distribution similar to  $280 \text{ k}$ . For space target, can assume that the earth is a uniform thermal radiation balance, namely the earth atmosphere system absorbed solar radiation equals to the space radiation energy, the total radiation intensity of

illumination  $E_q$  of the earth's radiation in the space target position is as follows:

$$E_q = \frac{4\pi \cdot R_q^2 \cdot M_q}{4\pi(R_q + h)^2} = \frac{R_q^2 \cdot M_q}{(R_q + h)^2}, \quad (18)$$

where  $R_q$  is the radius of the earth ( $6378.5 \text{ km}$ );  $h$  is the height of the target distance from the ground. So the ground radiation energy  $P^*_{(i,j)}$  absorbed by the number of  $(i, j)$  surface element in flake finite element is:

$$P^*_{(i,j)} = \frac{\varepsilon_q \cdot R_q^2 \cdot M_q \cdot S_{(i,j)} \cdot F_{q,(i,j)}}{(R_q + h)^2}, \quad (19)$$

where  $\varepsilon_q$  is the target surface absorption rate of the earth radiation;  $F_{q,(i,j)}$  is the angle coefficient of the surface of micro element to the earth radiation.

Analyze the above derivation process and result, Indirect solar radiation and the earth and its atmosphere system radiation impact of flame signal, mainly due to the changes in radiation angle coefficient, when increasing the radiation angle coefficient, radiation energy produced by these two factors will rise and reducing the sensitivity of infrared detector.

### 3.3. The Influence of Incident Angles

In the outdoor environment, the emergency fire is random, diversity and dispersion [16]. In the whole field of optical system of the infrared detection system, Flame location is uncertain and presents the characteristics of random so the flame not in the main axis of the optical system in most cases. The size and shape of the flame also has the difference and the flame shape differences make the distribution of flame thermal radiation energy imbalance [17]. In the field of optical system at a time is likely to produce several flame signals and their distribution has the characteristics of dispersion [18]. For such a flame signal, it will reduce the flame radiation energy for that deviate from the main optical axis of optical system. So it is very meaningful to study the radiation energy into the incident angle of optical system [19].

Assume that the test environment is a uniform brightness bright observation. Transient flame produced in different locations in the area of the infrared detector. The image aperture angle of the imaging plane's image point outside of the axis in the infrared detector is smaller than image aperture angle on the axis. The illumination of the image point outside of the axis is less than on the axis. So it will produce the different change of luminous flux on the photoelectric detector.

Assume that  $E'$  is the light of imaging plane's image point outside of the axis,  $E_0'$  is the light of imaging plane's image point on the axis,  $\omega$  is the deviation angle of image outside of the axis, Fig. 3 is the optical path.

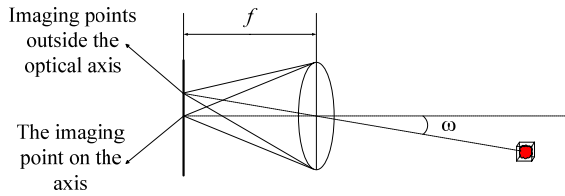


Fig. 3. Light path diagram.

The photometric formula is:

$$\frac{E'}{E_0'} = \cos^4 \omega, \quad (20)$$

The relationship between Optical volume and radiant quantity can be converted by the following formula:

$$E_v = \int_{\lambda_1}^{\lambda_2} K_m \cdot V(\lambda) \cdot E_e(\lambda) d\lambda, \quad (21)$$

where  $E_v$  is the brightness;  $E_e$  is the radial brightness;  $\lambda$  is the wavelength;  $\lambda_1$  and  $\lambda_2$  are the infrared detector wavelength's upper and lower limits respectively;  $K_m = 683 \text{ lm/W}$  is the absolute spectral luminous efficiency value of monochromatic light values;  $V(\lambda)$  as the spectral luminous efficiency function. Only select a peak wavelength value  $\lambda_0$  in the response spectrum of the infrared detector, so the above formula can be simplified as follow:

$$E_e = \frac{E_0'}{K_m \cdot V(\lambda_0)}, \quad (22)$$

$$E_{e0}' = \frac{\cos^4 \omega}{K_m \cdot V(\lambda_0)} \cdot E_0', \quad (23)$$

where  $E_e'$  is the irradiance of the image point outside of the axis;  $E_{e0}'$  is the irradiance of the image point on the axis. We can get the radiation energy relationship between the image point outside of the axis and on the axis from the relationship between irradiance and the radiant energy, as follow:

$$\frac{P_e'}{P_{e0}'} = k \cdot \cos^4 \omega, \quad (24)$$

where  $P_e'$  is the radiant energy of the image point outside of the axis;  $P_{e0}'$  is the radiant energy of the image point on the axis;  $k$  is a constant.

According to the formula (14), Off-axis imaging point detector output voltage and the axis of the imaging points on the relationship between the detector output voltages is derived, such as the following formula:

$$\frac{V_e'}{V_{e0}'} = \frac{\xi \cdot P_e'}{\xi \cdot P_{e0}'} = k \cdot \cos^4 \omega, \quad (25)$$

where  $V_e'$  is the detector output voltage outside the axis of imaging point;  $V_{e0}'$  is the detector output voltage on the axis of imaging point.

We can draw the conclusion based on the above analysis. When the flame signal passing the optical system but it is not on the main optical axis direction of the optical system, so output voltage of infrared flame detection system is conform to the attenuation relationship in the formulas (25). It indicate that off-axis imaging deviation angle of flame signal is larger, the greater the energy attenuation and the lower the sensitivity of infrared detector.

#### 4. Simulation

Based on the infrared target detection model is established in the second quarter, through the simulation, analyze the relationship between the various parameters of the system and characteristics of the detected infrared target. For the involved simulation parameters we use the following numerical calculation. Assume that the response rate  $\xi$  of the detector is  $5 \times 10^2 \text{ V/W}$ , the detection rate  $D^*$  of the detector is  $2 \times 10^8 \text{ cmHz}^{1/2} \text{ W}^{-1}$ , the detector photosensitive surface area  $A_d$  is  $2.6 \times 2.6 \text{ mm}^2$ ; the focal distance  $f$  optical system is 50 mm, the aperture  $D$  of optical system is 1.8, the transmittance  $\tau_0$  of the optical is 0.8; the bandwidth  $\Delta f$  of the system is 500 Hz. The finite element length  $a$ , wide  $b$  of the transient flame is 25 cm.

At this time, the relationship between the light detector output voltage  $V_s$ ,  $a$  and  $b$  as shown in Fig. 4. The finite element length  $a$ , wide  $b$  of the transient flame variation between 1 cm to 25 cm. The slope of the graph simulation of curved surface rendering is raising trend, when transient flame finite element area is gradually increasing, detector output voltage with larger amplitude increase. Figure show that when the transient flame signals are smaller, detector output voltage will decrease sharply, thus increasing the detector for transient flame detection more difficult. When transient flame fixed volume, under the premise of without changing the parameters

of detector, in order to improve the detector detect ability, need to adjust the optical system parameters such as focal length and field of view angle, thus reducing the background area and increase the light of relative area, achieve the purpose of improving the sensitivity of the detector.

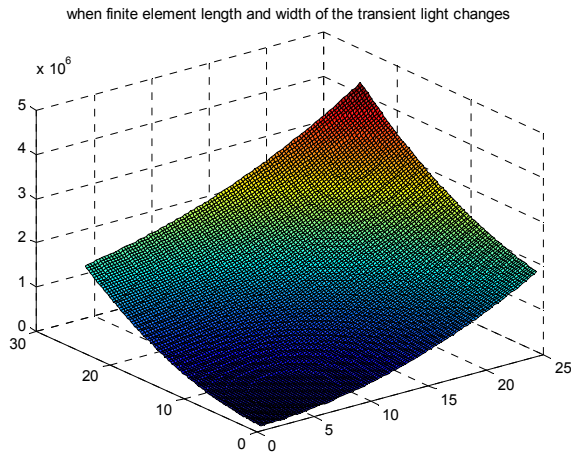


Fig. 4. The relationship of output voltage with the finite element length and width of the transient flame.

Shown in Fig. 5, the detection rate  $D^*$  of the detector variation between  $1 \times 10^8 \text{ cmHz}^{1/2} \text{ W}^{-1}$  and  $5 \times 10^8 \text{ cmHz}^{1/2} \text{ W}^{-1}$ , the detector photosensitive surface area  $A_d$  is changes in the range  $0.4 \times 0.7 \text{ mm}^2$  to  $6 \times 6 \text{ mm}^2$ . At this time, the relationship between the light detector output voltage  $V_s$ ,  $D^*$  and  $A_d$  as show in the follow:

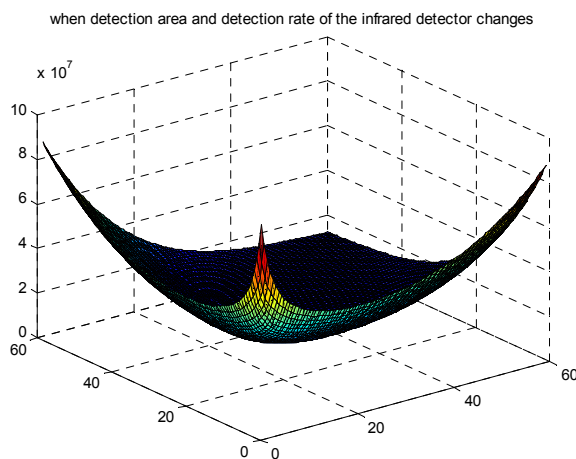


Fig. 5. The relationship of output voltage with detection area and detection rate of the infrared detector.

Figure in the simulation of curved surface concave downward trends, when the infrared flame detector when the detection area and the rate of increase, the output of the detector voltage drop

dramatically, falling fast to slow down after a certain level. This means that the other parameters unchanged, the infrared detector detecting area and the detection rate increased at the same time, will reduce the performance of detector probe. Infrared probe of the detection area and the detection rate, and when they will change an another constant, the surface first presents the downward trend, showed a rising trend after reach the minimum. Therefore detection area of the infrared detector and infrared detector detection rates are mutually restricted, on the premise of other parameters unchanged, fixed detection rate selection suitable area, detector detecting capability can be effectively improved.

As shown in Fig. 6, the detector photosensitive surface area  $A_d$  is changes in the range  $0.4 \times 0.7 \text{ mm}^2$  to  $6 \times 6 \text{ mm}^2$ , the bandwidth  $\Delta f$  of the system changes within 10 Hz to 1000 Hz. At this time, the relationship between the light detector output voltage  $V_s$ ,  $A_d$  and  $\Delta f$  as show in the figure.

Through the analysis of the changing rule of the diagram surface can be obtained, when the detection area of the infrared detector and the bandwidth of the system increase at the same time, the output of the detector voltage increases. When the system bandwidth and infrared detector of the detection area is lower, the infrared detector to transient flame signal detection ability drop, detector sensitivity decreases. In the case of external conditions do not change, increase the detection area of the infrared detector and system bandwidth, can make increase the detection sensitivity of detector.

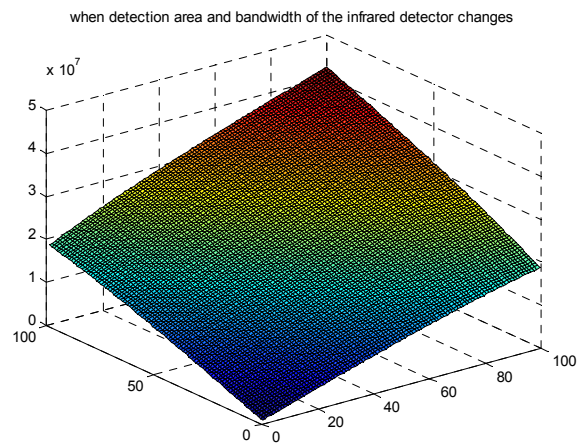


Fig. 6. The relationship of output voltage with detection area and bandwidth of the infrared detector.

As a result, in transient flame signal under the premise of a certain size, in order to improve the detection of infrared detector ability, need the following measures: (1) increase the focal length of the optical system, reduce the optical system of the viewing angle, so as to reduce the background area, relatively increased the transient flame area by optical system; (2) the detection rate in infrared

detector under the premise of increasing the detection area of the infrared detector, at the same time, increase system bandwidth. Through such measures can in detecting distance transient flame detection, effectively improve the detection ability and sensitivity of detector.

## 5. Test and Analysis

Through the analysis of the results of the simulation calculation, the measures to improve the detect ability of infrared detector. Even at the same time cooperate with transient signal disposal circuit of fire detection system. This effect is shown in Fig. 7, Fig. 7(a) is Infrared detector by choosing inappropriate focal length and the viewing angle of the optical system, the infrared detector to obtain the transient flame, its output voltage signal, using the integrated operational amplifier constitute general amplifier circuit, using high speed data acquisition instrument output waveform in figure. As you can see in the picture, noise signal is more, to produce a great impact on the later data processing, but also seriously affect the detection sensitivity of infrared detector.

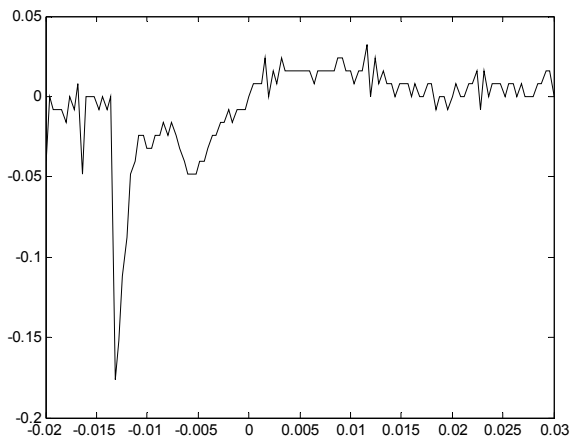


Fig. 7 (a). The influence of the detection signal by optical system.

Fig. 7(b) is according to actual detection range, selection focal length and field of view angle of appropriate optical system, the infrared detector output voltage signal, and uses the instrument amplifier circuit for signal filtering and amplification, etc., using high speed data acquisition instrument output waveform in figure. Compared with (a) the waveform can be clearly observed in addition to a lot of noise effects, and probes into the voltage signal amplification processing, laid a solid foundation for data processing.

The test select the detection rate  $D^*$  is  $5 \times 10^8 \text{ cm}(\text{Hz}^{1/2}\text{W}^{-1})$ , the response rate  $\xi$  is  $1.0 \times 10^5 \text{ V/W}$ , the detector photosensitive surface

area  $A_d$  is  $6 \times 6 \text{ mm}^2$ , the transient flame is 50 meters from infrared detector. Experiment tests two different transient flames, the first transient flame (a) flake finite area is  $25 \times 25 \text{ cm}^2$  and the second transient flame (b) flake finite area is  $15 \times 15 \text{ cm}^2$ . Fig. 8 is the change waveform of infrared detector output voltage displayed by the oscilloscope. In the graph, we can obviously observe that the different transient flame area produce the difference detection results.

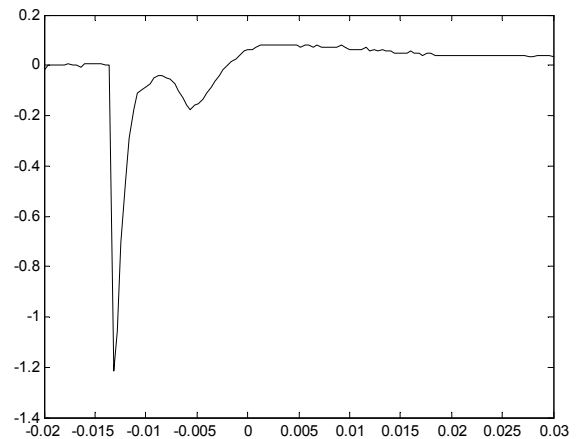


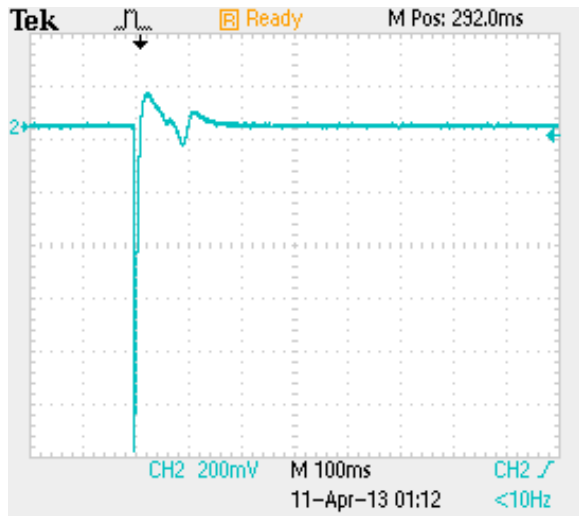
Fig. 7 (b). The influence of the detection signal by conditioning circuit.

Through the analysis of experimental data, when other parameters are given fixed values, the detection of different finite element area of the transient flame, the detector output voltage change at the same time. The tendency of the voltage consistent with the simulation of surface, simulation result is consistent with the change of voltage value. The mathematical model derived from the above has been verified its feasibility.

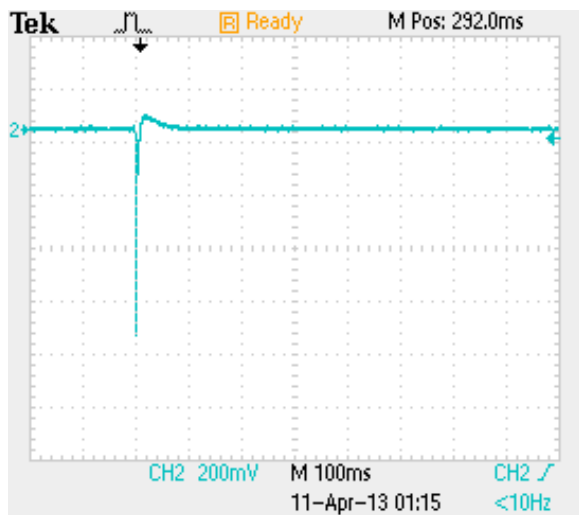
According to section 3.3 of the theory analysis and calculation of the transient flame into the optical system of the incidence angle is different, will cause the angular aperture of image space change, thus changing the luminous flux of photoelectric detector size. According to the relationship between the irradiance and the radiant energy, was derived through further off-axis imaging point and imaging point on the axis of the relationship between the radiation energy. As shown in Fig. 9(a) is the incident angle of impact test schematic diagram, infrared detector separately collected three positions of the transient flame signal, three locations in the same horizontal line, the horizontal line and the surface of the detection of infrared detector is a parallel relationship, at the same time the distance is 10 meters. The position "1" is the axis of the main optical axis optical system, with the linear distance of detection of infrared detector is 10 meters; Position "2" with the linear distance of detection of infrared



detector is 20 meters, the off-axis like deviation angle is  $60^\circ$ ; "3" position with the linear distance of detection of infrared detector is 25 meters, the off-axis like deviation angle is  $66.422^\circ$ .



(a)

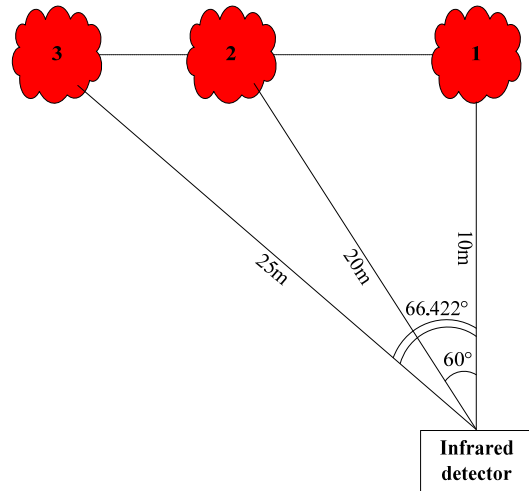


(b)

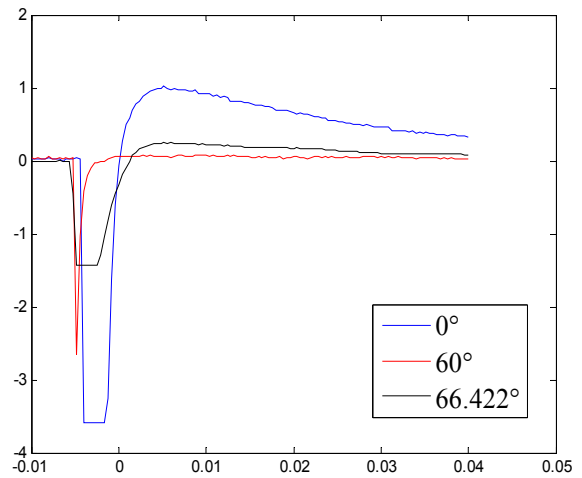
Fig. 8. Oscilloscope display signal.

The following experiment with the position relations, detector parameters are fixed, and other external parameters remain the same. As shown in Fig. 9(b) is the experimental data, three waveform figures are respectively in the three position detection for transient flame signal voltage curve. Through the analysis of experimental data, three positions taken by the transient waveform characteristics of the flame signal with a consistent, the attenuation rule of voltage composite theory calculation and analysis results. Due to three different voltage values of the same time, Infrared detector output voltage outside the optical axis of image point and infrared detector output voltage in the optical axis of the imaging

points on the value of correlation coefficient  $k$  through formula (25) can be calculated. Substituting the data into the formula, the results of the calculated is  $k = 14.431$ . When the flame detection system is not allowed to detect target, all calculated transient flame signal energy is converted into voltage values, can make use of formulas (25). If too much energy loss so that need to be aimed at the infrared target, to increase the detection sensitivity of infrared detector.



(a)



(b)

Fig. 9. The influence of different incident angle.

Apply the curves of numerical fire detector output voltage form high speed data acquisition instrument changes with time. Analysis the infrared detector output voltage by using the high time resolution of high speed data acquisition instrument. The experimental data and the simulation result are consistent. When we Increase the detector's detection range, reduce the transient fire area and increase the threshold voltage in the same time, we can also guarantee  $|V_s - V_N| \geq V_0$ , this improve the sensitivity

of the detector effectively. Infrared detector output voltage is affected by the transient flame area size, and this is consistent with the theoretical analysis. Verify the feasibility of transient flame calculation method of transient flame contribution to optical imaging system.

## 6. Conclusions

Focusing on the problem of fire detector sensitivity calculation, this paper presents a segmentation processing method of calculating transient flame radiation derived from the infrared detector using finite element analysis. To obtain the contribution of transient fire unit area to the infrared detector, the study of calculation method for optical imaging system contributes to the transient flame and establishes the computing model of the transient fire area produced by infrared detector to detect the fire area. Also, through calculating the light radiation and background radiation, we obtain the energy flux on the infrared detector. Last, we analyze the environmental factors effect on the flame detection by testing the factors affecting the infrared detector sensitivity by simulation, and the results verify the feasibility of the calculation method. In conclusion, this paper provides a calculation model for calculating the contribution of transient flame to optical image system, and a theory basis for improving the transient sensitivity of fire detection system.

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