# The upgrade heat flux sensor application for early fire detection

S V Klochkov<sup>1</sup>, A N Minkin<sup>1,2</sup>, S N Masaev<sup>1</sup>, A A Krekhov<sup>1</sup>

<sup>1</sup>Siberian Federal University, 79, Svobodny Prospekt, 660041, Krasnoyarsk, Russia <sup>2</sup>Siberian Fire and Rescue Academy, 1, Severnaya str., 662972, Zheleznogorsk, Russia

E-mail: TheRealArts@mail.ru

Abstract. The paper focuses on the description of the characteristics of the upgrade heat flux sensor, as well as the consideration of various models of its application to identify the source of combustion. The device uses a photovoltaic cell used to determine the thermal radiation intensity. The value thus defined is subsequently digitized and applied to determine the location of the radiation source. Among other things, this enables to use the device for finding the fire coordinates in order to extinguish it effectively using robotized fire complex. It is proposed to upgrade the device, which is to extend the temperature range of operation, and also to increase the speed and number of detectors in the line. The paper also provides a structural diagram of the functional sensor elements. A patent has been received for an improved device. Since the photovoltaic cell of a new sample with improved properties is used in the device, the article also provides an analysis of its characteristics, influence curves of the intensity of the heat radiation source on distance, as well as lines of constant signal strength. The data obtained were used to create three types of fire detection models, depending on the geometric parameters of the protected premises and the location of the combustible content source.

## 1. Introduction

According to the results of the study given in [1, 2], the heat flux sensor (HFS) can be considered to be a sufficiently effective device for detecting fires at the early stage. This device is protected by a patent (RF Patent No. 45544 U1, priority date: 2004.08.10, publication date: 2005.05.10) and has the following technical characteristics:

Characteristics	Characteristic value
1. The number of possible addresses for one direction on RS-485	31
2. Maximum sensor removal from the control module, up to, m	1200
3. Operation mode	continuous
4. Bit rate	9600, 57600
5. Current consumption at minimum supply voltage, mA	30
6. Direct current supply voltage, V	9 - 18
7. Operating temperature range, °C	-40 +55

Table 1. HFS technical characteristics.

8. Controlled area a solid angle, not less, degrees	90
9. Power consumption by the sensor, not more, W	0,3
10. Sensor sizes, mm	Ø54 x 120
11. Sensor mass, not more, kg	0,25
12. Average sensor service life, not less, years	10

To increase the device applicability for detecting fires, the following improvements are proposed: • temperature range expansion for the device operation;

• speeding;

• increase in the total number of devices in the line.

#### 2. Description of the proposed solution

The ability to operate at low temperatures is achieved by using a resistor to heat the internal space of the case, and increasing the signal processing speed due to the use of a high-performance universal processor, ARM 32-bit Cortex<sup>TM</sup>-M3. An increase in the total number of detectors in the communication link is facilitated by the use of an improved interface microcircuit RS-485. Thus, the functional diagram of the device is presented in Figure 1.



**Figure 1**. Functional diagram of the heat flux sensor: 1 - photovoltaic semiconductor radiation detector; 2, 7 - operational amplifiers; 3 - universal processor; 4 – crystal oscillator; 5 - RS-485 interface microcircuit; 6 - heating resistor; 8 - temperature sensor; 9 - voltage regulator; 10 – screw terminal; 11 - sensor power supply.

A photovoltaic semiconductor radiation detector (1) detects the heat flux of a fire or explosion. The signal from the radiation detector is amplified by an operational amplifier (2). The amplified signal is sent to the analog input of a high-performance universal processor ARM 32-bit Cortex<sup>TM</sup>-M3 (3). The processor frequency standard is set by a crystal oscillator (4) and is 8 MHz. According to the specification, this value is sufficient to take values from the analog input of the processor up to 400 times per second. The value received from the photoelectric detector is digitized by an analog-to-digital converter built into the processor (which makes it possible to obtain a range of values from -2048 to 2047) and is transmitted to the fire alarm control panel (5) with a 12-byte data packet. Thus, when using a high-performance universal processor, the maximum possible number of references per second to the fire alarm control panel at a speed of 375 Kbit/s and a line length of up to 500 m will be (taking into account delays) about 40 times per second (subject to the availability one device per line), which enables sufficient performance for fixing the fire or explosion process [3, 4, 5]. Sending a data packet by the

device is accompanied by a LED flash, which allows one to visually control the device operation. The internal space of the proposed device is heated by a resistor (6), additionally installed in the device electric circuit and receiving power from an operational amplifier (7) under the control of a processor (3).

In this case, the technical and economic efficiency of the device is due to:

1. Reducing losses from emerging fires and explosions due to accurate and quick determination of their sources and stages [3, 4].

2. Reducing the cost of installing a fire alarm due to the increased number of connections with additional sensors on the line.

3. Reducing the cost of heating the protected premises, necessary for the normal functioning of fire alarm devices.

This solution was registered by the authors in the Federal Service for Intellectual Property (RF Patent No. 195452, priority date: 2019.06.18, publication date: 2020.01.28).

In view of the application of a photovoltaic cell in HFS, which is different from that considered in [2], additional tests are required to determine its characteristics. In this work, the experiment described in detail in [2] was re-conducted the point of which is that the detector was located at a height of 1 m and at a distance of 10 m from the walls in a room with the same thermal background. At the same time, the room temperature varied from -40 to +30 °C. A ball with a diameter of 0.3 m was used as a source, a stable temperature on the surface of which in the range of 100 - 400°C was maintained by using a heating element located in the center of the ball. The homogenous heating was controlled by a group of thermocouples. At the beginning of the experiment, the ball was located on a suspension at a distance of 0.25 m from the detector case so that the center of the ball was located opposite the optical axis of the sensor. After reaching the average level of heat flux within a margin of 5%, the value was fixed, and the source moved away by another 0.25 m, after which the experiment was repeated



**Figure 2**. The dynamics of the change in the heat flux for a temperature of 100°C in the distance range 0.1 - 8 m from the detector for the received data (blue line) and the approximation function (red line).

As in [2], the approximation function is defined in the form of an exponential function of the form:  $M(d) = e^{ad+b} + c$ (1) For the applied photovoltaic cell, the values of a and b are equal to -0.7 and 7.67, respectively. The value of the parameter c is close to 0; therefore, it can be neglected.

The dynamics of changes in the value of the heat flux depending on the location of the source relative to the optical axis of the sensor remained unchanged and is described by the formula:

$$f(\alpha) = \frac{M}{2} (\sin\left(\frac{5}{2}\alpha - \frac{3}{4}\pi\right) + 1)$$
 (2)

where M – value on the optical axis of the detector,  $\alpha$  – angle of rotation.

Having fixed the value  $f(\alpha)$ , it can be defined:

$$d(K,\alpha) = \frac{1}{\alpha} \left( \ln\left(\frac{2K}{\sin\left(\frac{5}{2}\alpha - \frac{3}{4}\pi\right) + 1}\right) - b \right)$$
(3)

where d – distance from heat flow source to sensor,  $\alpha$  – device rotation angle.

To reduce the consumption of computing power, the approximation d by a simpler function is described:

$$d(K,\alpha) = \pi \left(\alpha - \frac{\pi}{2}\right) + \frac{1}{\alpha} (\ln(K) - b) \tag{4}$$

Formula (4) gives a sufficiently small error comparatively (3) (Figure 3).



**Figure 3.** A trajectory of motion that gives the same value of HFS for a test source of heat flux at a distance of 4m (left) and 0.6m (right) for (3) (blue) and (4) (red).

#### 3. Device application in fire detection models

Thus, having analyzed [4-7] and based on the characteristics of the device under consideration, the following models of its use as a system for early fire detection are possible:

**Net method.** The key point of this method is that the detectors in the protected room are mounted in two mutually perpendicular branches as shown in the figure below:



Figure 4. Net method.

In case of detecting an excess of the thermal background level due to the beginning of the combustion process, in each of the branches it is selected by the sensor with the highest rate. Since the coordinates of each device are known in advance, determining the coordinates of the heat flux source becomes a trivial task. Also, based on (2) and (4), taking into account the values of neighboring HFSs, it is possible to estimate the area *F* by analyzing the shapes of the curve values of *ABC* and  $A_1B_1C_1$ . This method is suitable for the protection of large rooms, the hot load of which is distributed closer to the floor level, for example, unloading areas of warehouses, theaters, and sports facilities [6].

**Oncoming method.** This method is presented by a pair of sensors located in the opposite direction on the same axis:



Figure 5. Oncoming method.

Since the value of the heat flux is related to the distance to its source by the formula (1), and it is almost always located on the optical axis of the sensors, it is quite simple to determine the "width" *AB* of the heated section. This method is suitable for the protection of corridor-type rooms, the space between the shelving of warehouses, etc.

**Projection method.** This method involves the placement of a combustible load conditionally in one plane.



Figure 6. Projection method.

Given the installation height and the tilting angle, for each sensor, the projection line (4) on this plane can be determined. Since two such lines obviously have up to 4 intersection points, then 4 detectors are enough to determine the coordinates of F. The advantage of the method is a smaller number of HFSs in comparison with the net method; however, it requires high quality of device installation, especially regarding tilt and rotation.

Since in the general case the combustible load may not be located in the same plane or at the floor level, methods for determining the position of the heat flux source become relevant. Further studies will be devoted to this problem, the results of which will be a set of proposals for introducing HFS in [8].

# 4. Conclusions

Thus, during the work, the upgrade heat flux sensor was presented, capable of operating in a wide temperature range and having increased speed. For this detector, the parameters necessary for its use as an early fire detection system were determined and models of such systems were proposed.

## References

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