THE DEVELOPMENT OF OPERATION ALGORITHM OF HEAT DET ECTOR WITH VARIABLE RESPONSE PARAMETERS

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***Abstract* — It have been identified, that there are objects where ambient air temperature changes not only as a result of fire, but also due to the operation of process equipment and harsh climatic conditions. These changes affect the timing of work for the fire detector. These facilities include boiler rooms, kitchens, dryers, vehicles, and more. The article substantiates the need to develop a heat detector that would change its firing parameters and at the same time does not contradict the regulatory requirements for its class. Algorithms for the operation of a heat detector are proposed, which changes the value of the static firing temperature and the rate of temperature rise at which it triggers. The algorithm of operation analyzes the speed of raising the ambient temperature without information about the operating modes of the process equipment and sets new values of the operation based on the analysis.**

***Keywords* — fire alarm system, fire detector, heat detector, rate of rise heat detectors, fixed temperature heat detectors, static response temperature**

I. INTRODUCTION

Ефективна робота системи пожежної сигналізації (СПС)

The effective operation of a fire alarm system (FAS) generally depends on the correct selection and placement of fire detectors (FD), which should ensure a reliable detection of the fire at an early stage of development. Choosing and placing the fire detectors must be taken into account: the purpose and category of protected premises; features of technological process; equipment on site; materials that make up the fire load in the control area; directions of possible fire spread; space-planning characteristics of the room; ventilation and heating working process; placement and type of electrical networks, heating devices in a controlled room, etc. In addition, the effective operation of the FAS depends on how effectively the algorithms of the FD operation are developed and programmed, what kind of triggering criteria are chosen as the basis, and how these criteria are met, how the seasonal, daily or hourly change in the triggering threshold of the FD is implemented. Creating a FD algorithm that allows early detection of fire and error-free working process is considered a difficult task. The basis for the problem solution is in the compromise between the time of fire detection and the probability of false alarm. The greater sensitivity of the FD to the controlled signs of fire, also means the greater likelihood of false alarm.

The working algorithm for the block of fuzzy correction of intelligent point combined FD with heat and smoke sensors is developed in the work. It allows you to detect a fire at an early stage of development based on the established forms and parameters of input and output membership functions and illegible rules. Using a neural network, an intelligent detector algorithm has been developed that takes into account various environmental parameters, including temperature, to detect a fire. In this work mathematical model is developed to optimize the time of operation of the heat substation for use in long and narrow rooms.

It is believed that heat FD (Fig. 1) has a higher inertia compared to smoke detectors and flame detectors. However, they are most effective in the case where a significant fire capacity with intensive heat release at the initial stage is foreseen, as well as when other types of detectors cannot be used because there are factors that can lead to their false positives. For example, due to the low smoke-forming capacity of combustible materials; when the spread of smoke is difficult; when there is a high concentration of any aerosol particles in the air that have nothing to do with the combustion process; because of the dustiness of the premises, etc. In general, heat detectors have a greater resistance to adverse environmental conditions than have other types.

Fig. 1. Heat detector

Heat detectors are rate of rise detector and fixed temperature detector (static detector). Selecting the type of FD that you want to install on the facility is a hard task. For this purpose it is necessary to consider the class of detectors with values of their typical and maximum application Temperature, minimum and maximum static response temperature, in accordance with the requirements of BS EN - 54-5: 2017 [4]. Clause 6.4.3 Technical Specification CEN / TS 54-14: 2018 [5] sets out the requirements that the designer must follow in the process of selecting FD. Differential heat detectors are more efficient than normal maximum heat detectors. They are more suitable for use when the ambient temperature is low. In some cases, they can compete with the smoke detector for efficiency. However, rate of rise heat detectors are more sensitive and can produce false alarms with significant temperature fluctuations due to technological processes and climatic conditions.

False alarms from rate of rise heat detectors may also be caused by a rapid temperature increase to normal room conditions following exposure to low temperatures [4]. Such a sequence may occur, for instance, in a loading bay of vehicles, airplane equipped with large doors to the outside: in winter, when the door is opened, the detectors are cooled, and after the door is closed there is a sharp rise in temperature.

Fixed temperature detector works more steadily in conditions of considerable temperature fluctuations in short periods of time. They are chosen in the way that the minimum static operating temperature would exceed the normal operating temperature (not more than 29°C [4]) and the maximum operating temperature (not more than 4 °C [4]). It is clear that the smaller the difference between the minimum static operating temperature and the operating temperature, the greater the likelihood of erroneous operation. Such situations can be prevented by installing detectors with a correspondingly higher triggering temperature. At the same time, with the increase of this difference, the detection time of fire of heat detectors increases as well.

There are a large number of facilities where heating is not provided. It is forbidden to use heat detectors with static response temperature on sites where the temperature is below 0°C, because the detection of fire by such detectors is delayed compared to the fire detection that can occur at positive temperatures. Then it turns out that depending on the time of year and the temperature of the air, it is necessary to constantly change the class of heat FD.

In [6-8], the display time of detectors was determined, depending on different types of detectors and different test conditions. The trigger time was estimated by the trigger time index and depended on the type of detector selected and its location. The dynamic characteristics of heat detectors in the time and frequency domains are determined on the basis of the transfer function [9].

There are facilities where the choice of heat FDs requires taking into account the rate of the ambient temperature change while remaining within the range of temperatures of use, not only from the effects of climatic conditions but also from the impact of process equipment. These include kitchens, boiler rooms, glass-roofed rooms, metal-coated attics and more. It is forbidden to install maximum-differential heat FD in such premises.

At the same time, there are facilities where the temperature changes very quickly over a short period of time and may even go beyond the temperature ranges of detectors, such as drying chambers; closed parts of process equipment; premises where relevant technological processes occur without human involvement; motor compartments of vehicles. This rapid change in temperature affects the time of fire detection on heat detectors.

According to statistics, a significant number of fires occur on vehicles [10]. They can last for several hours and can be operated in different temperature conditions. Statistical studies show that about two-thirds of vehicle fires originate from the engine compartment [11-13]. During the full-scale studies presented in [14-16], it was found that the correct operation of both heat and smoke fire detectors is significantly dependent on their location and movement of air flows in the engine compartment, and the detection of fire at the early stage of development is a problematical.

In the works [17-19] comprehensive studies of temperature and convective modes in the vehicles hood are presented and it is found that the temperature of the engine elements can reach 100 °C and the exhaust manifold 260 °C. Directly, the air temperature in the engine compartment reaches 80-120 °C, and the short-term peaks near the turbocharger and exhaust manifold 180-190 °C [20]. At the same time, when the vehicle is not in operation, its temperature is equal to the ambient temperature and may be, for example, -30 °C. All this affects the timing of the fire. Then it turns out that, depending on the conditions of operation, it is necessary to change the class of thermal FD.

Summarizing the above, there is a situation where the minimum static temperature of the heat FD is required to be changed in the same way as the smoke level of the FD at the program level, which is easier and does not require additional costs. Therefore, developing an algorithm for working with heat detectors that will ensure correct operation in difficult temperature conditions and detecting a fire at an early stage of development is a difficult task that will help to improve the fire state of the objects. At the same time, such a heat detector must comply with current regulations [4].

The necessity to adjust the level of the threshold of the actuation at the structural or program-technical levels was discussed in [21].

II. PROBLEM STATEMENT

The purpose of the work is to develop and study the algorithm of operation of the heat FD, which, depending on the environmental conditions, would automatically change the value of the static temperature of the actuation and the value of the rate for temperature increasing at which it operates. Thus, this algorithm will reduce the time of fire detection. Such detectors can be used in facilities where the ambient temperature changes very quickly in a short time due to the working process, as well as in facilities where the temperature depends on the rapid change of climatic conditions, for example, in non-heating rooms, cargo compartments of vehicles. , glass roofed rooms, metal-coated attics, etc.

III. SOLVING THE PROBLEM

As a result of the industrial development of microprocessor technologies, there are fundamentally new ways of processing information of FD. They contain a microprocessor with their own non-volatile memory. Since the sensing elements form analog signals, and the microprocessor works with signals in digital form, the design of the FD includes analog-to-digital converters. The algorithm is programmed in the microcontroller. It manages the measurement process and processes the results, using a modern mathematical apparatus (algebra of logic, indistinct logic), on the basis of which he decides on the presence of fire.

The use of microprocessors in the detectors made it possible to implement any algorithm of operation without changing the elemental base, so that , simplified the process of implementation for the developed algorithm of operation.

We will develop an operation algorithm for the heat sensor of the FD, which changes the static temperature value of the actuation and the value of the increasing rate of temperature at which the detector is triggered. This algorithm will allow to take into account the change in ambient temperature not only from the influence of climatic conditions, but also from the influence of technological equipment. The block diagram of the developed algorithm of heat FD operation is shown in Fig. 2. The first time the FD is switched on, it performs self-testing of its basic elements, checks the communication with the fire control unit (block 2). When a fault of its elements is detected at the output of the detector, an electrical signal is generated about the fault of the FD. If during the testing we do not find any malfunctioning elements of the FD, we will get a signal, for example, the LED glow in a certain color. In the memory of the microprocessor of the FD, by using control panel, we can record the time $\tau_{кор}$, through which the value of the static temperature of the detector operation, the maximum value of the temperature and the maximum speed of raising the ambient temperature at the object due to the operation of technological equipment, so called the technological temperature $T°_{тенх}$ and the technological rate of increase in the temperature $T°'_{тенх}$, which are greater than the temperature and the rate of change of the ambient temperature $T°_{сер}$ to the influence of climatic conditions (block 5).

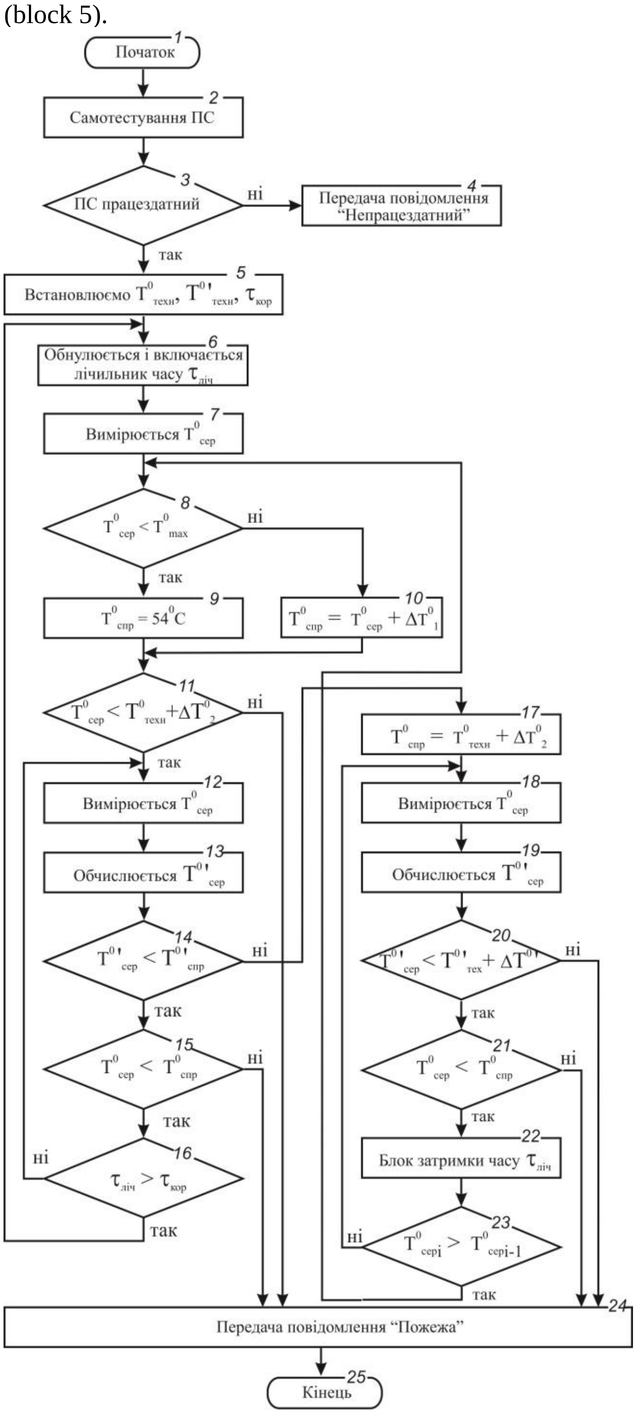

Fig. 2. Algorithm flowchart of heat FD operation with variable operating parameters

In the next step, the time counter (block 6) is reset and switched on. It is necessary in order to be able to adjust the value of the minimum triggering temperature of the FD depending on the change in temperature due to the influence of climatic conditions. You can set, for example, an hourly correction. In order that the proposed fire detector meets the requirements specified in the normative document DSTU EN - 54-5: 2017 [4], we shall refer it to class A2. Subsequently, it changes its static characteristics. This is not contrary to the requirements of DSTU EN - 54-5: 2017 [4]. Units 7 and 8 measure the ambient temperature of the $T°_{сер}$ object and compare the temperature with the maximum temperature of the FD $T°_{max}$. For class A2 $T°_{max} = 50°C$. If

$T^{\circ}_{сер} < T^{\circ}_{max}$, then go to block 9, where the minimum static trigger temperature for this class $T^{\circ}_{спр} = 54°C$ is set. If the condition $T^{\circ}_{сер} < T^{\circ}_{max}$ is not fulfilled, then we go to block 10, where the minimum static operating temperature of the FD $T^{\circ}_{спр} = T^{\circ}_{сер} + \Delta T_1^{\circ}$ (ΔT_1° – is the set temperature value, for example, the same 29 , which is specified in DSTU EN - 54-5: 2017 [2]) (block 10).

At this stage, it is also possible to implement an algorithm that will change the class of heat FD for which the value of $T^{\circ}_{спр}$, is already known, according to BS EN - 54-5: 2017 [4]. That is, Tspsp will be known in advance and will vary step by step depending on the operating conditions. Part of this algorithm is shown in Fig. 2. This is where the transition from class A2 to class B occurs, and if the condition is not fulfilled $T^{\circ}_{сер} < 65°C$, then class C.

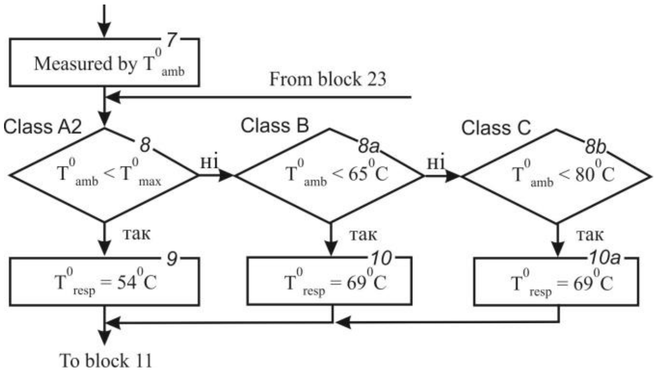

Fig. 3. Intelligent of Multi-sensory FD with of smoke and heat sensors 2251TMB

In block 11, the ambient temperature of the object is compared with the maximum temperature that may be on the object $T^{\circ}_{сер} < T^{\circ}_{техн} + \Delta T_2^{\circ}$ (where $\Delta T_2^{\circ} < \Delta T_1$ and can be, for example, the same 4 BS which are indicated in BS EN - 54-5: 2017 [4]. If $T^{\circ}_{сер} > T^{\circ}_{техн} + \Delta T_2^{\circ}$, a fire signal is generated at the output of the FD. If not, then the ambient temperature value of the object is again measured and the rate of its rise is calculated (blocks 12, 13). In block 14, the value of the rate of increase of the temperature of the medium $T^{\circ\prime}_{сер}$ is compared with the value of the rate of increase of the temperature $T^{\circ\prime}_{спр}$, , at which the FD is triggered, for example $T^{\circ\prime}_{спр} = 8°C/min$. If $T^{\circ\prime}_{сер} < T^{\circ\prime}_{спр}$, it means that the process equipment is not working and $T^{\circ}_{сер}$ is changing due to the impact on the climate of the climate. In block 15, the measured value of $T^{\circ}_{сер}$ and $T^{\circ}_{спр}$. If the condition $T^{\circ}_{сер} < T^{\circ}_{спр}$ spr is not fulfilled, then "Fire" is generated at the output of the FD. In this case, the FD operates as the maximum heat FD, that is, the rate of temperature rise due to the fire is less than the rate of temperature rise of the FD, and the value of $T^{\circ}_{сер}$ increases. If the condition $T^{\circ}_{сер} < T^{\circ}_{спр}$ is fulfilled, then we proceed to block 16, which compares the time of operation of the detector $\tau_{ліч}$ with the time taken to change the correction of the value of the minimum triggering temperature Ckor due to the change of the ambient temperature under the influence of climatic conditions. If $\tau_{ліч} < \tau_{кор}$, then go to block 12 and again - in a cycle, and if $\tau_{ліч} > \tau_{кор}$, то then the value of the minimum response temperature of the FD is adjusted, go to block 6.

When the process equipment starts operating or the temperature changes abruptly due to the weather, the temperature at the facility changes very rapidly ($T^{\circ\prime}_{сер} > T^{\circ\prime}_{спр}$). We proceed to block 17, where the maximum value of the minimum firing temperature P. is set. In block 18, the value $T^{\circ}_{сер}$, is again measured, and in block 19 the value of the derivative $T^{\circ\prime}_{спр}$ is calculated. In block 20, the value $T^{\circ\prime}_{сер}$ is compared to $T^{\circ\prime}_{мак}$, which is greater than $T^{\circ\prime}_{техн}$ ($T^{\circ\prime}_{мак} = T^{\circ\prime}_{техн} + \Delta T^{\circ\prime}$). If $T^{\circ\prime}_{сер} > T^{\circ\prime}_{мак}$, then at the output of the FD the signal "Fire" is generated, if not, we proceed to block 21 (the FD operates as the maximum detector), in which the $T^{\circ}_{сер}$ 3 $T^{\circ}_{спр}$. If the condition $T^{\circ}_{сер} < T^{\circ}_{спр}$ is not fulfilled, a "Fire" signal is generated at the output of the FD. If $T^{\circ}_{сер} < T^{\circ}_{спр}$, then through blocks 22 and 23 we pass to the control of the ambient temperature (block 18). The FD operates in cyclic mode. Blocks 22 and 23 are required to control the ambient temperature. If the temperature starts to decrease due to the stopping of the process equipment$T^{\circ}_{серi} < T^{\circ}_{спрi-1}$ (and - the integration step), then we move to block 8. The FD begins to operate under the initial conditions of its characteristics.

IV. IMPLEMENTATION MODEL IN MATLAB SIMULINK

The model of operation algorithm of the FDs heat sensor with variable operating parameters is developed on the basis of the block diagram shown in Fig. 2, was implemented in the Simulink software MATLAB. The developed model is presented in Fig. 4.

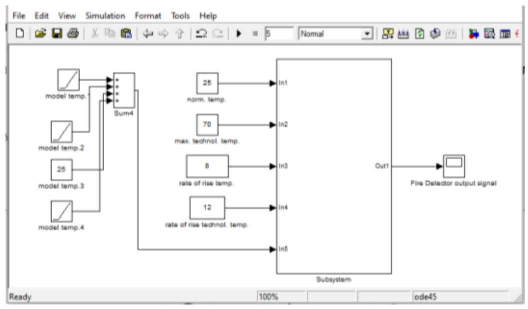

Fig. 4. Algorithm model of heat FD working process in MATLAB Simulink

In order to make sure that the proposed operation algorithm of the heat FD with variable triggering parameters works correctly. Since FD does not distinguish the reason for a change in the ambient temperature, we investigate different cases of temperature change.

Case 1. We simulate a situation where the temperature at the installation site of the FD is equal to $T^{\circ} = 25ºC$, and at a time t = 1 min there is an increase in temperature due to the fire, with a temperature increase of $T^{\circ\prime} = 6ºC/min$, which is less than the increasing rate of temperature alarm detector $T^{\circ\prime} = 8ºC/min$. The heat detector works as a fixed The following symbols are taken in the figure: curve 1 - temperature at the object (input signal acting on the FD); curve 2 - the rate of increase of temperature $T^{\circ\prime}$; curve 3 – FD output signal corresponding to logic "0" - FD is in standby mode, logic "1" is FD in "Fire" mode. When the room temperature reaches a minimum static firing temperature of 54 ºC (t = 5.8 min), the FD will go into Fire mode. FD operates according to the algorithm in cyclic mode (blocks 12-16) and does not go to block 17 (Fig. 3).

Fig. 5. Simulation results of FD operation when the temperature changes due to fire: curve 1 - indoor temperature; curve 2 is the rate of increase of temperature $T^{\circ\prime}$; curve 3 is the output signal of the FD.

Case 2. Let's investigate how the FD will work if the ambient temperature changes due to the operation of process equipment. The simulation results are shown in Fig. 6. The temperature at the place of installation of the heat detector $t^o = 25^oC$, after t = 1 min there is an increase in temperature with the rate of increase of temperature t = 1 min відбувається збільшення температури зі швидкістю підвищення температури $T^{\circ\prime}=5^oC/min$. At the time t = 2.5 min the process equipment starts to work and there is a sharp increase in temperature with the rate of temperature increase $T^{\circ\prime} = 10^oC/min$. If the FD did not change its firing parameters, it would cause the FD to go into Fire mode. According to the algorithm of work, we proceed to block 17. A new value of the minimum static operating temperature $T^{\circ}_{спр} = T^{\circ}_{техн} + \Delta T_2^{\circ} = 70\ ^oC$. The rate of temperature rise $T^{\circ\prime} = 10^oC/min$ is less than $T^{\circ\prime}_{мак} = T^{\circ\prime}_{техн} + \Delta T^{\circ\prime} = 12^oC/min$. As the temperature at the facility does not reach the new minimum static firing temperature, the FD is in standby mode.

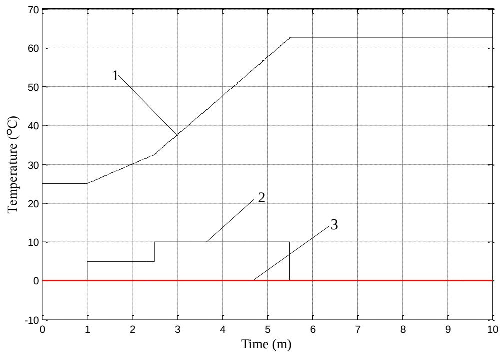

Fig. 6. Simulation results of FD operation when the temperature changes due to the operation of technological equipment: curve 1 - indoor temperature; curve 2 is the rate of increase of temperature $T^{\circ\prime}$; curve 3 is the output signal of the FD.

Case 3. Investigate how the FD will work if the ambient temperature changes due to the fire at a rate of increase in temperature $T^{\circ\prime} = 10^oC/min$. The simulation results are shown in Fig. 7. The temperature in the room $t^o = 25^oC$, after t = 1 min there is an increase in temperature with the rate of increase in temperature $T^{\circ\prime}=5^oC/хв$. At time t = 2.5 min, the temperature $T^{\circ\prime} = 10^oC/min$ begins to rise rapidly. According to the algorithm of work, we proceed to block 17. A new value of the triggering temperature $T^{\circ}_{спр} = T^{\circ}_{техн} + \Delta T_2^{\circ} = 70\ ^oC$. $T^{\circ\prime} = 10^oC/min$ less than $T^{\circ\prime}_{мак} = 12^oC/min$. As the temperature at the object continues to increase, at the time t = 6.25 min the temperature reaches the new minimum static firing temperature $T^{\circ}_{спр} = 70\ ^oC$, the FD goes into "Fire" mode. The heat detector works as a fixed temperature detector.

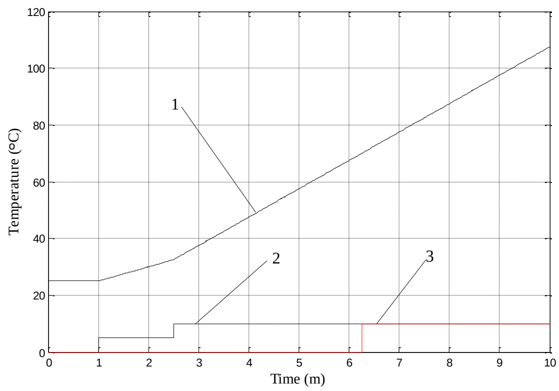

Fig. 7. Simulation results of FD operation, when the temperature changes due to fire, the FD operates at the triggering temperature: curve 1 - indoor temperature; curve 2 is the rate of increase of temperature $T^{\circ\prime}$; curve 3 is the output signal of the FD.

Case 4. Investigate how the FD will work if the ambient temperature changes with the rate of temperature rise $T^{\circ\prime} = 14^oC/min$. The simulation results are shown in Fig. 7. The algorithm of operation of the FD is the same as in the previous case, but when checking the condition $T^{\circ\prime} < T^{\circ\prime}_{техн} + \Delta T^{\circ\prime}$ block 20 Fig. 2) the FD goes into the mode "Fire". The heat detector works as a heat detector with a rate of rise in temperature elements. (The FD operates as a heat detector with an element of temperature rise).

Fig. 8. Simulation results of the operation of the FD, when the temperature changes due to fire, FD operates at a rate of temperature rise: curve 1 - indoor temperature; curve 2 is the rate of increase of temperature $T^{\circ\prime}$; curve 3 is the output signal of the FD.

V. CONCLUSIONS

The timing of ignition detection and the likelihood of FDs false alarms from third-party sources are significantly influenced by the conditions in which they are operated. An algorithm for the operation of a heat detector has been developed, which changes the value of the static firing temperature and the rate of temperature rise at which it triggers. These values are changed based on an analysis of the ambient temperature change rate without information on the operating modes of the process equipment. This allows them to be used on sites where environmental temperature changes and their rate of rise are not only due to severe climatic changes but also due to the operation of process equipment.

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