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Сформульовано критерій оптимізації самоналагоджувальних сповіщувачів. Розроблено алгоритми та структура таких сповіщувачів. Їх відмінною рисою є можливість ефективного застосування в невизначених умовах для довільних і заздалегідь невідомих горючих матеріалів. Верифікація запропонованих сповіщувачів свідчить про їх здатність забезпечувати раннє гарантоване виявлення осередків загорянь різних матеріалів в заздалегідь невідомих умовах

Ключові слова: самоналагоджувальний пожежний сповіщувач, гарантоване виявлення загоряння, горючий матеріал, порогове значення, верифікація

Сформулирован критерий оптимизации самонастраивающихся извещателей. Разработаны алгоритмы и структура таких извещателей. Их отличительной чертой является возможность эффективного применения в неопределенных условиях для произвольных и заранее неизвестных горючих материалов. Верификация предложенных извещателей свидетельствует об их способности осуществлять раннее гарантированное обнаружение очагов загораний различных материалов в заранее неизвестных условиях

Ключевые слова: самонастраивающийся пожарный извещатель, гарантированное обнаружение загорания, горючий материал, пороговое значение, верификация

DESIGN OF FIRE DETECTORS CAPABLE OF SELF-ADJUSTING BY IGNITION

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1. Introduction

More and more attention is paid today to creating self-learning fire detectors (FD) for the systems of automated fire-prevention equipment (SAFE), capable of adjusting to fuzzy and changing operating conditions. For such conditions, it is impossible to design in advance the optimal SAFE with predetermined parameters [1, 2]. Actual statistics of loss-causing fires testify to the fact that operating conditions of SAFE on modern sites are varied and unpredictable. In this regard, designing the SAFE with predetermined parameters, which would provide their guaranteed fire protection, is not feasible.

The main information source on the ignition on sites for SAFE are FD. Contemporary FD generate information about ignition based on various physical components of combustion [3]. Great requirements to the ignition detection are put forward to thermal FD, which are widely used in various early detection systems when initial dynamics of growth of ambient temperature is considerably disguised by random thermal disturbances. That is why it is becoming increasingly important to create self-learning thermal FD, capable of improving their functioning, providing guaranteed detection of an ignition source under various and unpredictable conditions of using diverse flammable materials.

Relevance of the present work implies the design of thermal FD capable of self-adjusting by ignition of materials, with guaranteed detection of an ignition source under conditions of application that are unknown in advance.

2. Literature review and problem statement

Existing FD for SAFE do not ensure guaranteed detection of an ignition source under arbitrary conditions of their use at real sites. That is why the problem has been examined lately on designing FD, capable to operate effectively under uncertain dynamic conditions of ignition at sites, taking into account a priori information about random disturbances.

Paper [4] proposes to solve this problem within the framework of designing multi-sensor FD based on the principles of fuzzy logic. Fuzzy logic is known to be based on the representation of uncertainty of operation conditions as fuzzy magnitudes with the assigned membership functions. Under actual conditions of ignition, such information is typically missing. With this approach, the problem of guaranteed detection of ignition source under uncertain conditions, which is important for SAFE, remains unresolved. In addition, fuzzy logic of ignition detection is a complex process of generation of fuzzy rules, whose implementation is difficult for modern microcontrollers and microprocessor-based computational tools.

Article [5] considers one of the methods for ignition detection under conditions of uncertainty based on neural technologies. Finding an optimal solution of ignition detection remains an unsolved problem. In addition, the search for an optimal solution can be interrupted, even if this is not determined, for example, in the case of using an unrepresentative sample for neural network training, or if there is no appropriate function for learning. The implementation of artificial neural networks is complex while learning is rather lengthy. In this case, guaranteed ignition detection under conditions of uncertainty is not provided.

Paper [6] examines technologies of multi-criterial ignition detection at a site, taking into account several factors of a developing fire. The studies were performed for the assigned statistics of random disturbances. The tasks of guaranteed ignition detection and FD training in the absence of information about the laws of fire factors distribution remain the unresolved parts of the problem.

A number of studies [7, 8] focus on the design of new algorithms for ignition detection using fuzzy logic and neural networks to improve reliability of fire recognition at a site. The research is limited to the case of the assigned statistics of observation. In this case, unresolved are the problems of guaranteed ignition detection and construction of learning FD under conditions of lacking information on the laws of distribution of the observed data.

Study [9] examines a principle of group usage of FD at a site. Results of the research are limited to the known statistics of observations. It is noted that under these conditions, FD grouping and the use of information on topology of their location make it possible to improve quality of fire detection. However, the problem of guaranteed fire detection is not considered, and its solution remains to be found.

A problem on improving the accuracy of FD under real ignition conditions at sites is the focus of article [10]. In this case, the studies are limited to the assigned Gaussian statistics of background fluctuations, whereas peculiarities of the implementation of guaranteed fire detection are not considered.

It has been mentioned recently in promotional materials that the company SystemSensor (headquartered in the USA) designed FD of the next generation, the type of Acclimate 2251TMB (Canada) [11]. According to the company-developer Mircom (Canada), such FD differs from the known ones in that it is self-learning. Its intelligent capabilities allow self-adjusting to the application conditions, unknown in advance. Acclimate 2251TMB is a combined targeted FD that combines optical and temperature channels. In this case, the temperature channel has a fixed threshold while sensitivity of the optical channel changes automatically. Embedded software analyzes data from both channels and, based on a specialized algorithm of self-learning, decides whether there is or there is no ignition at the site.

Official statement of the company Mircom (Canada) [11] states that the probability of false triggering of such FD approaches a negligible magnitude. At the same time, the microprocessor is constantly analyzing the air mix composition in the premises, adjusting the threshold indicator of opacity, which allows avoiding false triggering caused by the effect of dust. However, the intelligent algorithm itself is not described in promotional materials. It is only stated that FD starts operation only in the case of a real fire. However, guaranteed indicators of the quality of fire detection are not considered and the values are not given.

There is also promotional information from ZAO "PO "Spetsavtomatika" (Russia) about new FD of the aspiration type for super early fire detection, which are capable of self-adjusting to unknown conditions at a particular site. However, the problems of guaranteed ignition detection and the self-adjustment algorithms of such FD are not considered.

Paper [2] explores the algorithms and structural circuits of learning FD for various methods of registration of basic physical ignition components. In this case, effectiveness of FD learning and guaranteed fire detection by them depends essentially on both initial conditions and parameters of learning algorithms and the type of flammable material of ignition (type of a fire load at a site).

Thus, unresolved part of the problem is the development of FD capable of self-adjusting by different kinds of ignition.

3. The aim and objectives of the study

The goal of present study is to design FD capable of self-adjusting by ignition, which would provide guaranteed ignition detection of various types of combustible materials under conditions that are unknown in advance.

To accomplish the goal of research, the following objectives were formulated:

– to formulate a criterion for the guaranteed detection of ignition of combustible materials;

– to determine algorithms and structural circuits of fire detectors capable of self-adjusting by ignition;

– to verify fire detectors capable of self-adjusting by ignition on the example of actual dynamics of the mean medium temperature at ignition and combustion of various flammable materials in the form of alcohol, paper, wood, and textile.

4. Formulation of criterion for the guaranteed ignition detection by fire detectors

Any object of fire protection is characterized by a certain fire load, which is basically determined by the amount of combustible materials and properties. The dynamics of development of an ignition source depends not only on a fire load at a site, but also on the access of oxygenated air, that is, on air exchange at a site. An ignition source at the initial stage of its development is usually considered as a source of basic physical components in the form of heat, smoke, and carbon monoxide. That is why early ignition detection at a site can be based on these components.

Next, we shall introduce a general concept of guaranteed ignition detection by FD. By the guaranteed fire detection by FD at a site, we shall imply such ignition detection, at which complete probability of FD triggering $P(x \in X_1)$ at a site is equal to the probability $P(f \neq 0)$ of actual ignition or

$$P(x \in X_1) = P(f \neq 0),\qquad(1)$$

where x is the magnitude of the observed ignition component at a site (heat, smoke, carbon monoxide); X_1 is the region of values of magnitude of an observed ignition component, relevant to existence of a fire source and FD triggering; f is the state of an ignition source at a site that may take value $f \neq 0$ (an ignition source exists) or $f = 0$ (an ignition source is absent).

Complete probability of FD triggering may be represented in the form:

$$P(x \in X_1) = P(x \in X_1 : f = 0) + P(x \in X_1 : f \neq 0).\qquad(2)$$

In this case, a probability of actual ignition at a site will be determined by magnitude

$$P(f \neq 0) = P(x \notin X_1 : f \neq 0) + P(x \in X_0 : f \neq 0).\qquad(3)$$

Considering relations (1)–(3), we shall obtain

$$P(x \in X_1) - P(f \neq 0) =$$
$$= P(x \in X_1 : f = 0) - P(x \notin X_1 : f \neq 0) = 0.\qquad(4)$$

The resulting equality (4) means that the introduced notion of guaranteed fire detection at a site (1) for any arbitrary component is equivalent to the equality of probabilities of false and failed ignition detection, that is,

$$P(x \in X_1 : f = 0) = P(x \notin X_1 : f \neq 0).\qquad(5)$$

Therefore, the criterion of guaranteed ignition detection of various flammable materials at a site can be formulated in the form of equation (5) of the probabilities of false and failed fire detection and for an arbitrary physical component of a corresponding fire source.

5. Development of algorithms and structure of fire detectors capable of self-adjusting by ignition

In order to determine the algorithms and structural circuits of FD capable of self-adjusting by arbitrary physical components x of ignition, providing guaranteed detection of ignition sources at a site, we shall consider a characteristic function of the following form:

$$\theta(x,c) = \text{sgn}(x-c) = \begin{cases} 1, \text{ if } x \geq c, \\ 0, \text{ if } x < c, \end{cases}$$

where c is the threshold value. It should be noted that mathematical expectation of characteristic function $M\{\text{sgn}(x-c)\} = =P(x \in X_1)$. Assuming that the occurrence of ignitions at a site is a rather rare case, it can be argued that probability $P(x \notin X_1 : f \neq 0)$ of missing an ignition in expression (5) is close to zero. That is why, in this case, the most probable is the magnitude

$$M\{\text{sgn}(x-c)\} = 0.\qquad(6)$$

Based on equation (6), we can determine discrete and continuous algorithms of operation of FD capable of self-adjusting by arbitrary physical components of x ignitions. If the registered components of ignition of materials x[i] arrive discretely, the algorithm of FD self-adjustment can be represented as a discrete dynamic procedure of threshold determining

$$c[i] = c[i-1] + g[i](\text{sgn}(x[i] - c[i-1])), \quad c[0] = c0,\qquad(7)$$

where g[i] is the parameter, chosen from the condition of convergence of discrete dynamic procedure; c0 is the original threshold value. In a general case, parameter g[i] must satisfy known general requirements, which are more of theoretical than of practical interest, due to the lack of specific recommendations on its determining. This means that for this parameter of procedure (7), there is some arbitrariness of the selection. Thus, the given parameter may be fixed or depend on the moment and magnitude x[i] of the observed component of the ignition of material. In this case, the magnitude of parameter g[i] exerts significant impact on the rate and accuracy of convergence procedure (7). The magnitude of original value of threshold c0 also produces a not less impact on the convergence of this procedure to the optimum threshold for various ignition components and materials.

Fig. 1 shows experimental dependences of conditions in a simulation chamber [2] at ignition and combustion of various materials (1 – alcohol, 2 – paper, 3 – wood, 4 – textiles). Magnitude Δt determines the interval of sequence of corresponding registered ignition components of the specified material, which was 0.1 sec.

The data shown in Fig. 1 indicate the need to provide adaptation of original value of FD threshold to current conditions of observation of specific registered ignition components for various materials. For this purpose, it is proposed to use the procedure of median filtering of registered data and to determine the original threshold value

$$c0 = \sum_{m=0}^{5} x[m] / 6 + 0.5.$$

In this case, as parameter g[i] of the convergence of procedure (7), it is possible to employ the fixed value of parameter g[i]=const, or the parameter, determined

$$g[i] = \left(\sum_{m=0}^{i} x^2[m] \right)^{-1}.$$

In the latter case, a certain adaptation of the original convergence of the procedure to the registered components of ignition of various materials is provided.
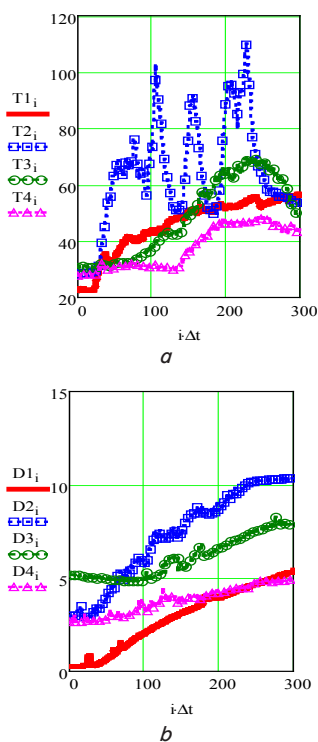
Fig. 1. Dependences of conditions in a simulation chamber:
a — temperature of gas medium; b — smoke density

In the case of continuous time t for arbitrary physical component of ignition of material $x(t)$, continuous algorithm of self-adjustment of FD threshold and guaranteed fire detection with regard to (7) can be represented in the form of corresponding differential equation

$$dc(t)\,/\,dt = g(t)(\text{sgn}(x(t)-c(t))), \quad c(0)=c0, \qquad (8)$$

where $g(t)$ is the function of time, satisfying known general requirements to convergence for continuous procedures of similar type; magnitude $c(0)$ determines the original threshold value in (8). Magnitude $c(0)$ is determined by the mean value of arbitrary physical component of ignition of material $x(t)$ in the initial interval of its observation

$$c(0) = \int_0^T x(t)\mathrm{d}t\,/\,T,$$

where T is the duration of interval for determining the original threshold value in procedure (8).

The block diagram of FD capable of self-learning by ignition of materials and guaranteed detection of ignition sources regarding procedure (8) is shown in Fig. 2. According to this diagram, data $x(t)$ about an arbitrary and observed component of materials ignition at a site arrive at the input of FD capable of self-learning by ignition. Based on data $x(t)$, original threshold value $c(0)$ and corresponding parameter of convergence of self-adjustment procedure (8) are calculated. At the output of a self-adjusting FD, the assessment forms of characteristic function $\theta(x,c)$ in the form of a corresponding sequence of zeros and unities that represent current assessments $\hat{P}\,(x(t)\in X_1)$ of non-observed probability $P(x\in X_1)$ of the guaranteed detection of an ignition source at a site. In this case, to determine a probability of guaranteed detection

of an ignition source by the proposed self-adjusting FD, it is necessary to calculate mathematical expectation of current assessment $M\{\hat{P}\,(x(t)\in X_1)\}$. It is possible to find mathematical expectation of the current assessment $\hat{P}\,(x(t)\in X_1)$, if we employ, for example, the current averaging operator $S_H\{*\}$ or exponential smoothing $E\{*\}$. Such operators are well known and described in detail in the scientific literature, which is why they do not need additional consideration.
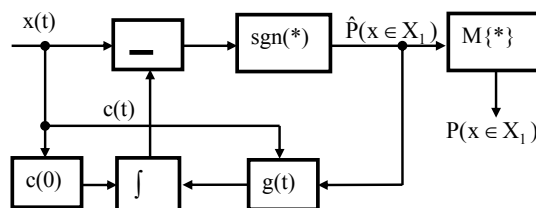

Fig. 2. Block diagram of FD capable of self-learning by ignition of materials for guaranteed detection of fire source at sites

We shall confine ourselves to the information about structure of the specified operators, which in our case take the corresponding form:

$$S_H\{x(t)\} = \int_{t-H}^{t} x(m)\,\mathrm{dm}/\mathrm{H}, \qquad (9)$$

$$E\{x(t)\} = \int_0^t \exp\left(-\frac{t-m}{H}\right) x(m)\,\mathrm{dm}/\mathrm{H}. \qquad (10)$$

In relations (9) and (10), magnitude H determines, respectively, an interval of averaging and a parameter of smoothing. Subsequently, in the process of verification of FD capable of self-adjusting by ignition of materials, both operators (9) and (10) will be used to calculate $M\{\hat{P}\,(x(t)\in X_1)\}$. It should be noted that at approximately equal effectiveness of operators, the implementation of $E\{*\}$ in continuous and discrete time proves to be easier. That is why operator $E\{*\}$ is widely used in various measuring systems to decrease errors in smoothing.

6. Verification of fire detectors capable of self-adjusting by ignition

Verification of FD capable of self-adjusting by ignitions was carried out based on the data, obtained during actual experiment at ignition and combustion of standard flammable materials shown in Fig. 2. Discrete data x_i on the components of ignition of different materials were registered by appropriate measuring sensors at time moments t_i, where $i=1, 2,..., 3000$. As the physical ignition components, we considered temperature, smoke density and the concentration of carbon monoxide in the medium, which were recorded using a personal computer and specialized software, which allows reading the sensors at various frequency. Measuring sensors were in the upper part of the chamber and enabled registration of the above-mentioned physical components of ignition of various materials.

The main purpose of verification was to check the claimed ability of the proposed FD, capable of self-adjusting

by ignitions, to execute guaranteed early detection of an ignition source under conditions unknown in advance. Such conditions were created in the simulation chamber at actual ignition and subsequent combustion of various types of flammable materials. An additional aim of verification was to study the impact of the proposed procedures on the calculation of probability of guaranteed detection of ignition source by FD. Such procedures include the ways of determining a parameter of convergence of the procedures of threshold self-adjustment, as well as operators of current averaging $S_H\{*\}$ and exponential smoothing $E\{*\}$.

Fig. 3 shows results of verification of the proposed FD capable of self-adjusting by temperature at ignition of various combustible materials. In this case, the parameter of convergence of procedure of self-adjustment of FD threshold changed according to the magnitude, determined

$$g[i] = \left(\sum_{m=0}^{i} x^2[m] \right)^{-1}.$$

Dependences, shown in Fig. 3, characterize dynamics of probability of guaranteed detection of ignition source. The data were obtained during implementation of operators of current averaging $S_H\{*\}=cM_i$ (averaging interval 0.5 s) and exponential smoothing $E\{*\}=P_i$ (parameter alf2 – 0.02). Verification of FD, self-adjusting by smoke density at ignition of various materials, was carried out as well. The most typical of the results of this verification are shown in Fig. 4 for wood and textiles.

Next, we carried out the verification of FD capable of self-adjusting by the medium temperature, but at a fixed parameter of convergence of procedure of threshold self-adjustment ($g[i]=0.05$). Results, characteristic to this case, are shown in Fig. 5 for wood and textiles.
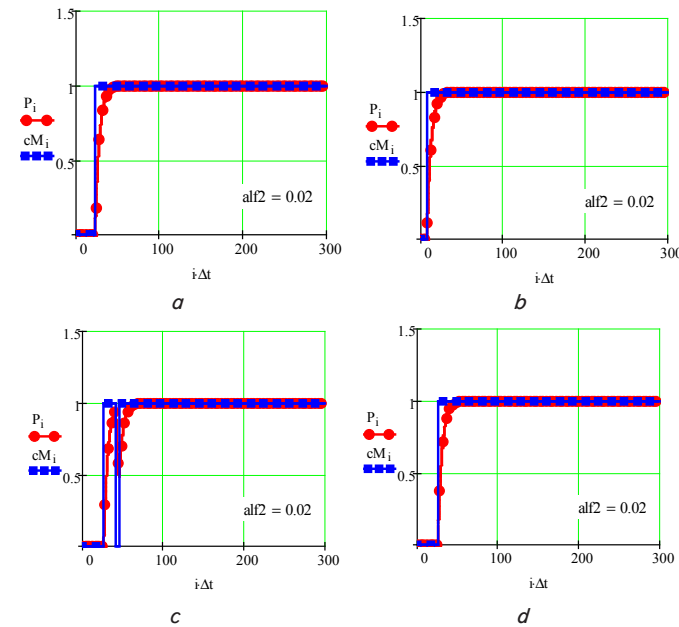

Fig. 4. Results of verification of FD self-adjusting by smoke density: a — wood; b — textiles

Fig. 3. Results of verification of FD capable of self-adjusting by the medium temperature: a — alcohol; b — paper; c — wood; d — textiles

Fig. 5. Results of verification of FD self-adjusting by the medium temperature, at fixed parameter $g[i]=0.05$: a — wood; b — textiles

For the same case, we conducted the verification of FD self-adjusting by smoke density. In this case, results that are characteristic for this situation are shown in Fig. 6 for alcohol and wood.
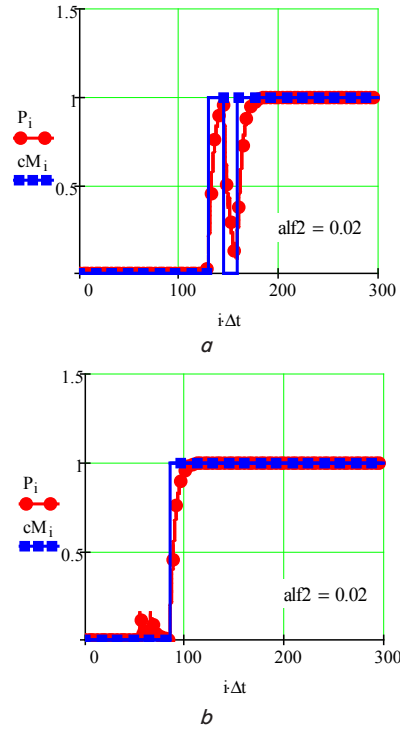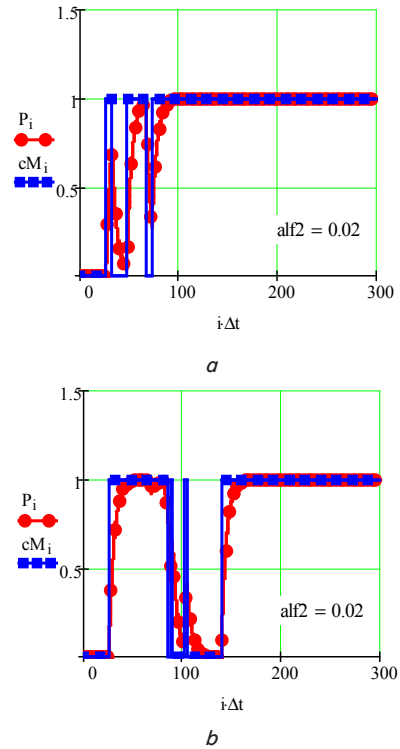
On the whole, presented results of verification indicate the capability of the proposed FD, self-adjusting by ignitions,

to provide guaranteed early detection of ignition sources at sites under conditions that are unknown in advance.
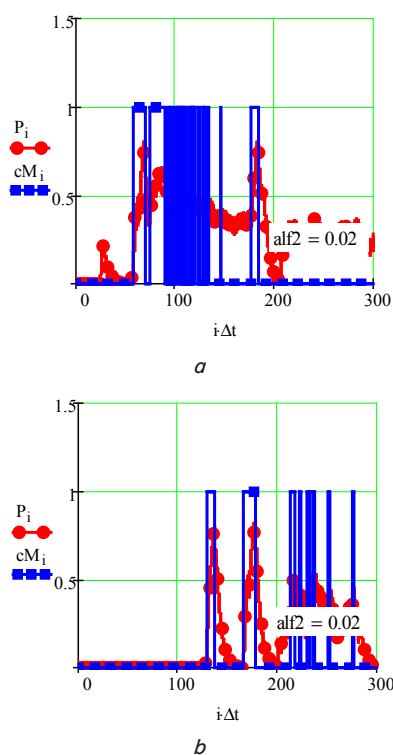

Fig. 6. Results of verification of FD self-adjusting by smoke density, at fixed parameter $g[i]$=0.05: a — alcohol; b — wood

7. Discussion of results of verification of fire detectors capable of self-adjustment by ignition

According to results of verification shown in Figs 3, 4, the proposed FD can provide guaranteed early detection of source of ignition of various materials under conditions that are unknown in advance. In the case of FD self-adjustment by smoke density, a guaranteed detection of the ignition source occurs at later moments after ignition of materials compared with the case of FD capable of self-adjusting by temperature. From analysis of the results shown in Fig. 5, it follows that at a fixed parameter of convergence of procedure of threshold self-adjustment by temperature under examined conditions, the time of guaranteed detection of ignition source increases. In this case, irregularity of original dynamics of probability of ignition source detection increases. It was noticed that the greatest irregularity is inherent to combustible materials, such as wood and textiles.

Application of the fixed convergence parameter in the procedure of threshold self-adjustment by smoke density causes substantial irregularity of dynamics of probability of ignition source detection. This leads to a decrease in the implemented magnitude of detection of ignition source.

It was established that if FD is self-adjusted by carbon monoxide concentration, it is possible to provide guaranteed early ignition detection. In this case, specified parameters of convergence of the procedure of threshold self-adjustment insignificantly affect dynamics of probability of ignition detection. This is explained by practically simultaneous ignition of material and emission of carbon monoxide. That is why, a concentration of carbon monoxide is a more preferable pattern for the guaranteed ignition detection in the explored types of combustible materials. It should be noted that FD capable of self-adjusting by ignition make it possible to provide a guaranteed level of detection of ignition of various combustible materials at sites under complex conditions that are unknown in advance.

8. Conclusions

1. We introduced the concept and proposed mathematical definition of the guaranteed detection of ignition by FD. Based on this, the criterion of optimization of FD capable of self-adjusting by ignition was formulated in the form of equality of probabilities of erroneous solutions, related to false ignition detection and a failure to register it.

2. Algorithms and structural circuits of FD capable of self-adjusting by ignition were determined. A characteristic feature of the algorithms is the implementation of a nonlinear dynamic procedure of data processing from the output of measuring sensor, arriving in real time, for the self-adjustment of threshold of guaranteed ignition detection. A distinguishing feature of the proposed structural circuit of FD capable of self-learning by ignition for guaranteed detection of an ignition source at sites is the presence in its structure of the units for determining the original value for guaranteed threshold and the current value of convergence parameter for a nonlinear dynamic procedure according to data of observations over the appropriate physical component of ignition of combustible material. In addition, the structural circuit of FD, capable of self-adjusting by ignition, includes the unit of formation of probability of ignition detection based on data from the output of the nonlinear processing unit. The indicated features provide invariance of FD self-adjustment to the observed components of ignition and the types of combustible materials.

3. Results of verification of the proposed FD indicate their capability to carry out early guaranteed detection of ignition sources of various types of combustible materials under conditions that are unknown in advance. In this case, it should be noted that for the examined types of combustible materials the FD, which self-adjust by the carbon monoxide concentration, prove to be more preferable than those self-adjusting by temperature or smoke.

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Розглянуто питання підвищення ефективності діагностики працездатності автоматизованих систем за допомогою експертних діагностичних систем на основі розробленого методу пошуку діагнозу на конфліктної множині вхідних даних. Пропонується використання математичних методів роботи зі структурою типу «m-арні кортежі на основі впорядкованих множин». Отримано математичні та графічні залежності мінімізації часу пошуку діагнозу для розробленого методу

Ключові слова: експертна діагностична система, діагностика відмов, структура організації даних, оцінка часу виконання алгоритму

Рассмотрены вопросы повышения эффективности диагностики работоспособности автоматизированных систем при помощи экспертных диагностических систем на основе разработанного метода поиска диагноза на конфликтном множестве входных данных. Предлагается использование математических методов работы со структурой типа «m-арные кортежи на основе упорядоченных множеств». Получены математические и графические зависимости минимизации времени поиска диагноза для разработанного метода

Ключевые слова: экспертная диагностическая система, диагностика отказов, структура организации данных, оценка времени исполнения алгоритма

EVALUATION TO DETERMINE THE EFFICIENCY FOR THE DIAGNOSIS SEARCH FORMATION METHOD OF FAILURES IN AUTOMATED SYSTEMS

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1. Introduction

In recent years, the way people control various kinds of technology has radically changed. The leading place in this process is taken by automated systems, SCADA (Supervisory Control and Data Acquisition) systems included. Modern SCADA systems are widely spread all over the world to control technological processes in different areas such as