11. Nogin, V. D. A simplified version of the analytic hierarchy method based on non-linear convolution of criteria [Текст] / V. D. Nogin // Zhurn. vychislit. matem. i matematich. fiz. – 2004. – Vol. 44, Issue 7. – P. 1259–1268. – Available at: http://www.apmath.spbu.ru/ru/staff/nogin/nogin_p11.pdf
12. Expert assessments for solutions developing [Electronic resource]. – Available at: http://books.ifmo.ru/file/pdf/817.pdf
13. Wang, H. An efficient quantum meet-in-the-middle attack against NTRU-2005 [Text] / H. Wang, Z. Ma, C. Ma // Chinese Science Bulletin. – 2013. – Vol. 58, Issue 28-29. – P. 3514–3518. doi: 10.1007/s11434-013-6020-y
14. Xiong, Z. An Improved MITM Attack Against NTRU [Text] / Z. Xiong, J. Wang, Y. Wang, T. Zhang, L. Chen // International Journal of Security and Its Applications. – 2012. – Vol. 6, Issue 2. – P. 269–274.

Розроблено та обґрунтовано метод підвищення швидкодії максимального теплового пожежного сповіщувача для складних умов використання. Цей метод заснований на динамічній корекції вихідного сигналу теплового датчика за допомогою інерційно-форсованої ланки з передаточною функцією. Постійну часу інерційної частини такої ланки змінюють за часом на інтервалі вимірювання температури

Ключові слова: максимальний тепловий пожежний сповіщувач, швидкодія, оточуюче середовище, складність температурних умов

Разработан и обоснован метод повышения быстродействия максимального теплового пожарного извещателя для сложных условий использования. Этот метод основан на динамической коррекции исходного сигнала теплового датчика с помощью инерционно-форсированного звена с передаточной функцией. Постоянную времени инерционной части такого звена изменяют по времени на интервале измерения температуры

Ключевые слова: максимальный пожарный извещатель, быстродействие, окружающая среда, сложность температурных условий

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DEVELOPMENT OF A METHOD TO IMPROVE THE PERFORMANCE SPEED OF MAXIMAL FIRE DETECTORS

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1. Introduction

Maximum thermal fire detectors (MTFD) are used as a primary source of information about fires at objects in different types of fire automatics systems. Based on the information from such devices, a warning signal is enabled in the systems of fire automatics about a fire at the object, as well as a controlling signal for the automatic fire extinguishing systems. In connection with a particular urgency of the task on early detection of fires, high demands are put forward in terms of high-speed performance of MTFD. This is especially true when initial dynamics of temperature rise in the environment is disguised as occasional perturbation.

Such perturbations are typically understood as rapid changes in temperature and significant fluctuations in the ambient temperature, which are characteristic for the warehouse and industrial premises, garages, commercial kitchens, etc. In this case, peculiarities in the environment and technological process do not make it possible to use other types of fire detectors. Traditional methods for improving high-speed performance of MTFD under dynamic temperature conditions are related to an increase in the level of random component of the output voltage. This is the main source for the cases when fires are missed or mistakenly detected [2].

The relevance of present work is in decreasing the time of fire detection at the objects with complex temperature conditions, reducing, at the same time, the probability of MTFD false triggering.

2. Literature review and problem statement

The existing thermal fire detectors are known, under real conditions, to demonstrate insufficient performance speed in determining temperature of the environment for a guaranteed detection of fires. Article [3] proved that according to the criterion of acceptable risk, the guaranteed detection of fires by individual fire detectors is possible only under very favorable conditions. These conditions correspond to low occasional perturbations in comparison with the dynamics in temperature of the environment. In this regard, there is an intensive research into finding constructive ways to improve performance speed of MTFD under real dynamic conditions with regard to occasional temperature perturbation. Paper [4] examined the possibilities of employing the methods of D-S theory. Using the methodology of sensory networks is tackled in article [5]. Methods of optimization of group of sensors for detecting the fires are considered in [6].

The synthesis of an optimal measuring device for the factors of fires with slow dynamics is the subject of article [7]. An analysis of these papers allows us to conclude that this direction of research is based on the use of a group (boundary set) of the same or different types of detectors and multichannel processing of their output data with the application of modern technologies [8]. Multicriterial technologies for detecting fires make it possible to process the output signals of fire detectors that measure several factors of the fire or different parameters in one of the factors (for example, an absolute value, the rate of increase or fluctuation). Most of the studies in this area are focused on processing the data from various types of detectors, placed in the same area of protection [9]. In this case, detectors operate with a controlled threshold of fire detection that is fixed in the interval of determining this factor. An issue of improving performance speed and accuracy of thermal fire detector is not considered at all in the above-mentioned papers, except for [7].

Another part of the studies concentrates on the development of new algorithms for fire alarm systems using fuzzy logic [10] and neural networks [11] for the more reliable recognition of events related to false detection of fires at a facility. Article [12] addresses the development of multicriterion detection of fire when using a similar type of sensors in a group, but positioned in different areas of the object of protection. It is shown that the grouping of sensors when receiving information with regard to the topology of their positions and implemented technology provides for overall high quality in the detection of fire at the facility. There are also technologies for placing [13] the fire detectors taking into account the peculiarities of topology of various types of protection [14].

The aforementioned studies are based on the introduction of structural redundancy and do not solve the problem of simultaneous improvement in performance speed and accuracy of particular thermal fire detectors. At present, this problem is solved mainly by the principle of group use of fire detectors at their low speed and accuracy.

Article [7] demonstrates that existing thermal sensors of fire detectors are non-optimal with low performance speed and accuracy. In this case, the shortcomings mentioned are the main cause for the increase in the time of detection and the number of false triggering about the fire on real objects.

A known method [15] for improving the performance speed of MTFD is based on the fact that the output signal of the MTFD thermal sensor in the interval of determining the temperature is subjected to dynamic correction with a transfer function of inertial-forced link. In this case, static transmission coefficient K_2 of the correction link is chosen to be equal to unity. Time constant T_1 of the forcing part of the link is selected to be equal to time constant T_d of a thermal sensor. And time constant T_2 of the inertial part is fixed in the interval of measurement and lower than time constant T_d. A drawback of this method [15] is the growth in fluctuations of the output signal of MTFD under conditions of temperature variability in the environment that occurs during actual fire on objects. This, in turn, reduces the accuracy of temperature measurement and increases the number of false triggering.

Thus, there is a need to develop a new method to improve the performance speed of MTFD, which would not include the shortcomings specified in the review. It will also make it possible under conditions of temperature fluctuations in the environment to provide for an improved performance speed of MTFD and simultaneous reduction in the fluctuations of output signal in the interval of determining the temperature.

3. The aim and tasks of the study

The aim of present work is to develop a method with improved performance characteristics of MTFD with a simultaneous reduction in the fluctuations of output signal under conditions of occasional thermal fluctuations in the environment in the interval of determining the temperature.

To achieve the set aim of scientific study, the following tasks are to be solved:

– theoretical analysis of the known method for improving the performance speed of MTFD under conditions of temperature fluctuations in the environment during fire in the interval of determining the temperature;

– theoretical substantiation of the new method for improving the performance speed of MTFD under conditions of temperature fluctuations;

– comparative analysis of the known and the proposed methods for increasing the performance speed of MTFD under conditions of temperature fluctuations.

4. Theoretical analysis of the known method for improving the performance speed of MTFD at temperature fluctuations

Assume that at the input of thermal sensor of MTFD at arbitrary time $t \in [t_0, t_k]$, ambient temperature is determined as

$$T_{cp}(t) = T_u(t) + n(t),$$

where $T_u(t)$ is the temperature of environment during the measured fire, n(t) are the random temperature fluctuations, which are characterized by a mean value M{n(t)}=0 and a correlation function

$$R(\tau) = 0{,}5N_0\,\delta(\tau),$$

$$\tau = t_2 - t_1, \quad t_2 > t_1,$$

where N_0 is the spectral density of temperature distortion, t_1 and t_2 are the arbitrary moments of time in interval $[t_0, t_k]$.

We shall assume that a transfer function of the thermal sensor of MTFD is determined

$$W_1(p) = \frac{k_d}{T_d p + 1},$$

where k_d is the static transmission coefficient of the thermal sensor used. In this case, a transfer function of the inertial-forced link, according to a well-known method [22], is determined by

$$W_2(p) = \frac{(K_2\,(T_1 p + 1)}{T_2 p + 1}.$$

In this case, the resulting transfer function of the MTFD thermal sensor with inertial-forced link will take the form:

$$W(p)=W_1(p)\,W_2(p)=$$
$$=\frac{k_d}{T_d p+1}\,\frac{k_2(T_1 p+1)}{T_2 p+1}=\frac{k_d}{T_2 p+1}. \quad (1)$$

In the temporal region, expression (1) will be matched by equivalent differential equation for signal y(t) at the output of inertial-forced link of the form:

$$\dot{y}(t)+ay(t)=ak_d T_{cp}(t) \text{ at } y(t_0)=y_0 \text{ and } a=\frac{1}{T_2}, \quad (2)$$

where y_0 is the value of output signal in time t_0.

Consider a typical example when

$$T_{cp}(t)=T_u+n(t),$$

where T_u determines constant measured temperature of the environment during fire (a priori unknown). In this case, at the output of inertial-forced link, according to (2), for the known technique at free time t of the interval of determining the temperature mathematical expectation of the signal

$$m_y^1(t)=m_y^1(t_0)\,e^{-\frac{t-t_0}{T_2}}+T_u\left(1-e^{-\frac{t-t_0}{T_2}}\right), \quad (3)$$

where $m_y^1(t_0)$ is the mathematical expectation of signal at the output of inertial-forced link at time t_0. The performance speed, which is provided by the known technique, according to (3), is determined by magnitude T_2^{-1}. Dispersion of fluctuations $D_y^1(t)$ of the output signal, in this case, according to (2), will be determined

$$D_y^1(t)=D_y^1(t_0)\,e^{-\frac{2(t-t_0)}{T_2}}+\frac{N_0}{4T_2}\left(1-e^{-\frac{2(t-t_0)}{T_2}}\right), \quad (4)$$

where $D_y^1(t_0)$ is the variance of signal fluctuations at the output of inertial-forced link at time t_0. Following (3) and (4), for interval $[t_0, t_k]$ of determining the temperature, which significantly exceeds the magnitude of time constant T_2, at the end of interval, we obtain, accordingly:

$$m_y^1(t_k)\approx T_u, \quad (5)$$

$$D_y^1(t_k)\approx\frac{N_0}{4T_2}. \quad (6)$$

Thus, following (5) and (6), the known method for improving the performance speed of MTFD under conditions of random temperature fluctuations is associated with an integral increase in the dispersion of signal fluctuations (6) at the output of inertial-forced link. In this case, performance speed improvement, which is associated with a decrease in time constant T_2, leads to an increase in the dispersion of fluctuations of the output signal of correction link. And this, in turn, leads to an increase in the number of false triggering of detector.

5. Theoretical substantiation of the method for improving the performance speed of MTFD at temperature fluctuations

Theoretical substantiation of the new method is based on the development of scientific base underlying its creation. Such a scientific base should provide for the development of such a method that is capable under conditions of temperature fluctuations in the environment during fire in the interval of determining the temperature to realize a more considerable increase in the performance speed of MTFD than the known method, as well as simultaneous reduction in the fluctuations of output signal of the sensor. In order to resolve the set problem in the interval of determining the temperature in MTFD, we proposed that output signal of the thermal sensor undergo dynamic correction with a non-stationary transfer function of the inertial-forced link, whose static coefficient K_2 is selected to be equal to unity. In this case, time constant T_1 of that part of the link that forces is chosen equal to time constant T_d of the thermal sensor, and a time constant of the inertial part of the link in interval $[t_0, t_k]$ of determining the temperature is changed by time t by arbitrary rule $T_2(t)$ from the magnitude T_{min} at the beginning of interval to the magnitude T_{max} at its end. At the same time, magnitude T_{min} is selected lower than time constant T_2, and magnitude T_{max} is chosen larger than time constant T_2. In this case, time constant $T_2(t)$ of the inertial part of the link is changed by time in the interval of determining the temperature by rule

$$T_2^a(t)=\begin{cases}T_{min}, & t_0\le t\le t_a,\\ T_{max}, & t_a\le t\le t_k.\end{cases} \quad (7)$$

According to rule (7), arbitrary time t_a is selected within time interval $[t_0, t_k]$.

Let us consider a theoretical substantiation of the method proposed. Improving the performance speed of MTFD, according to the proposed method, is based on the fact that the magnitude of time constant T_2 is not registered in the measurement interval $[t_0, t_k]$ but changed by the rule $T_2(t)$, according to (7). In the temporal region regarding a transfer function (4), whose time constant is changed by time, according to rule

$$T_2(t)=T_2^a(t),$$

the equivalent non-stationary differential equation for the output signal y(t) in the following form is true:

$$\dot{y}(t)+a(t)y(t)=a(t)k_d T_{cp}(t)$$

at

$$y(t_0)=y_0,\ \ a(t)=\frac{1}{T_2(t)}. \quad (8)$$

Mathematical expectation and dispersion of fluctuations in the output signal y(t) (8) of the inertial-forced link, in arbitrary time t_a in interval $[t_0, t_k]$, shall be determined in accordance with:

$$m_y(t_a)=m_y^1(t_0)\,e^{-\frac{t_a-t_0}{T_{min}}}+T_u\left(1-e^{-\frac{t_a-t_0}{T_{min}}}\right), \quad (9)$$

$$D_y(t)=D_y^1(t_0)\,e^{-\frac{2(t_a-t_0)}{T_{min}}}+\frac{N_0}{4T_{min}}\left(1-e^{-\frac{2(t_a-t_0)}{T_{min}}}\right). \quad (10)$$

According to (9), performance speed, which is provided by the proposed approach, is determined by magnitude

T_{min}^{-1}, which is larger than performance speed T_2^{-1}, since, according to rule (7), T_{min} is selected lower than T_2. With regard to (9), (10) and rule (7), in final moment t_k of time in interval $[t_0, t_k]$, mathematical expectation and dispersion of fluctuations in the output signal y(t) of the inertial-forced link, according to the proposed method will be determined

$$m_y(t_k) = m_y(t_a)\, e^{-\frac{t_k - t_a}{T_{max}}} + T_u\left(1 - e^{-\frac{t_k - t_a}{T_{max}}}\right), \tag{11}$$

$$D_y(t_k) = D_y(t_a)\, e^{-\frac{2(t_k - t_a)}{T_{max}}} + \frac{N_0}{4T_{max}}\left(1 - e^{-\frac{2(t_k - t_a)}{T_{max}}}\right). \tag{12}$$

For interval $[t_a, t_k]$, which exceeds the magnitude of time constant T_{max}, mathematical expectation and dispersion of fluctuations in the output signal y(t) of the inertial-forced link, at time t_k according to rule (7), that is proposed, will be determined according to (11) and (12),

$$m_y(t_k) \approx T_u \tag{13}$$

and

$$D_y(t_k) \approx \frac{N_0}{4T_{max}}. \tag{14}$$

Comparison (5) to (13) revealed that the mathematical expectation of output signal y(t) according to the known and the proposed methods at the end of the interval of determining the temperature at random temperature fluctuations coincide. And these values are equal to the magnitude of temperature of the environment T_u.

In this case, performance speed, which is ensured in accordance with the proposed method, becomes larger than that of the known one. According to method [15], increasing the speed of detector performance is carried out by reducing the magnitude of time constant T_2, which is fixed in the interval $[t_0, t_k]$. This leads to a corresponding growth in the dispersion of fluctuations (6) of output signal y(t).

According to the proposed method, improving the performance speed of MTFD is achieved at time constant $T_2(t)$, variable over time, according to rule (7), in the interval $[t_0, t_k]$ of measurement. This makes it possible, at the beginning of measurement interval, due to a lower magnitude T_{min}, to improve performance speed of MTFD more efficiently than in the known method. And, in this case, at the end of the interval, on the contrary, to decrease the fluctuations (14) of output signal y(t) due to a larger magnitude T_{max}. This, in particular, makes it possible, under conditions of significant temperature distortion and action of considerable temperature fluctuations in the environment, to enhance performance speed and at the same time to reduce fluctuations in the output signal of inertial-forced link. The known approach does not allow achieving it at all.

6. Discussion of results of comparative analysis of the existing and the proposed methods for improving the performance of MTFD

Severe temperature conditions of the environment were characterized by the random nature of the temperature of the environment, predetermined by the area of burning, as well as temperature fluctuations in the environment that disguise this temperature. At the first stage, we investigated the influence of change in the magnitude of time constant T_2 on the dynamics of dispersion of fluctuations in the output signal according to the known method of improving the performance of MTFD under different conditions. Fig. 1 shows dependence $D_y^1(t)$ on the magnitude of time constant T_2 under conditions of insignificant dispersion (0.2 °C^2) in the temperature of the environment, predetermined by the area of burning (T_u=50 °C). In this case, spectral density of temperature background N_0=100 (°C^2/Hz). The magnitude of ratio of mean energy of the temperature of the environment, predetermined by the area of burning, to spectral density of the temperature background (SNR) amounted to 5.

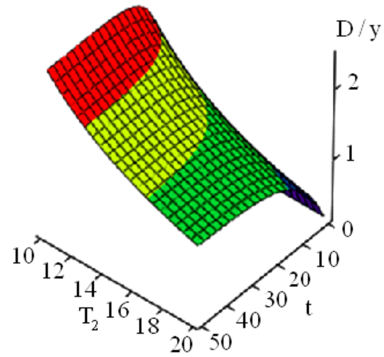
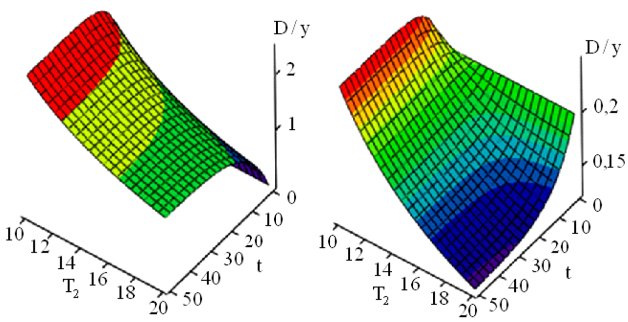


Fig. 1. Dynamics of fluctuation dispersion of the output signal of MTFD according to the known method depending on T_2 under conditions characterized by SNR=5

Similar dependences for different SNR values are shown in Fig. 2, *a, b*.

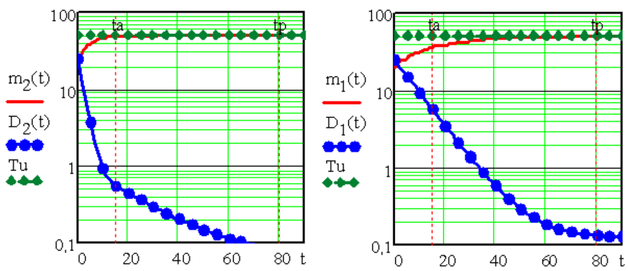


a *b*

Fig. 2. Dynamics of fluctuation dispersion of the output signal of MTFD according to the known method depending on T_2 under conditions that are characterized by different values of SNR: *a* – 1.6; *b* – 15.8

The results obtained confirm the conclusion that improvement in the performance speed of MTFD by the known method under complex temperature conditions leads to the increase both in dispersion of the output signal and in the number of false triggering of detectors. In addition, data in Fig. 2, *b* illustrate a well-known, and characteristic for all linear inertial systems, property of invariance in the parameters of the process at their output under a stable mode on the initial conditions.

A subsequent comparative analysis of the known and the proposed method was run for severe conditions that are characterized by a considerable dispersion in temperature (about 25 °C^2) and SNR=15.8. For the considered method, T_{min}=5 s, T_{max}=40 s, and time t_a=15.2 s. T_2, according to EN54, was selected equal to 20 s. Conditional time tp for the approval of a decision was 80 s. Fig. 3 shows quality indicators of the proposed and the known method under conditions specified above.

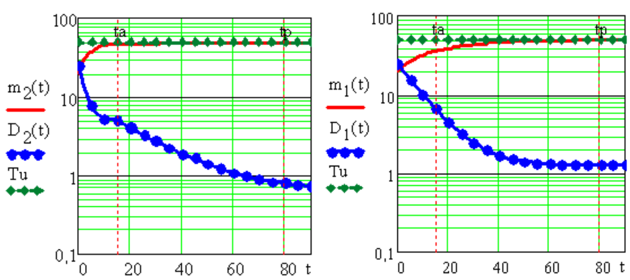


a *b*

Fig. 3. Dynamics of quality indicators (mathematical expectation and dispersion) of the output signal under complicated conditions of detecting a fire area SNR=15.8: *a* – proposed method; *b* – known method

Dependences shown in Fig. 3 indicate effectiveness of the proposed method for improving the performance speed of MTFD under difficult conditions, which are characterized by a significant dispersion of the measured temperature. Until the point of time 15 s, mean value of the output signal matches the magnitude of the measured temperature. Dispersion of the output signal in this case is 0.6 units. For the known method, until the point of time 15 s, this value is 76 % of the true magnitude of the measured temperature with dispersion at 6 units.

Fig. 4 shows similar dependences for even more severe conditions, under which, in addition to the significant temperature dispersion (25 °C^2), there are considerable temperature background fluctuations (SNR=5).



a *b*

Fig. 4. Dynamics of quality indicators (mathematical expectation and dispersion) of the output signal under complicated conditions for detecting a fire area SNR=5: *a* – proposed method; *b* – known method

We can conclude with regard to the aforementioned that up to 15 s, for the new method, mean value of the output signal matches the magnitude of the measured temperature. Dispersion of the output signal in this case is about 5 units. Similar data for the known method are 74 % and 7 units, respectively.

It should be noted that by increasing T_{min} to 8 s, it is possible to somewhat improve characteristics of MTFD under such conditions (Fig. 5).

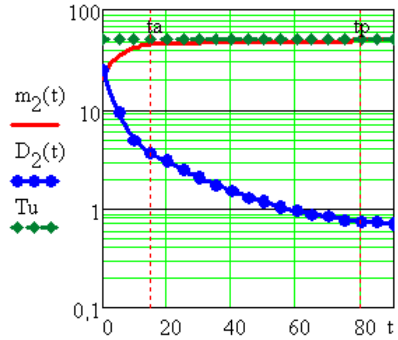


Fig. 5. Dynamics of quality indicators (mathematical expectation and dispersion) of the output signal according to the proposed method under complicated conditions for detecting a fire area SNR=5 and T_{min}=8 s

Data in Fig. 5 indicate that up to 15 s, the proposed method makes it possible to improve accuracy of determining the temperature from 74 % (Fig. 4, *b*) to 95 % and reduce the dispersion – from 7 to 3.5 units, respectively. Until the time a decision on the fire is made, both methods provide for a sufficient matching between the mean value of assessment with the magnitude of measured temperature; in this case, the proposed method allowed us to reduce dispersion by almost 2 times.

7. Conclusions

1. Theoretical analysis of the known method under the action of temperature fluctuations in the environment during fire in the interval of determining the temperature revealed that improving the performance speed of MTFD is possible only by reducing its time constant. It was found that the reduction of time constant in a detector leads to the rise in fluctuations of the output signal of MTFD. The latter causes reduced accuracy in determining the temperature, and increases the number of false triggering.

2. Theoretical substantiation of the new method for improving the performance speed of MTFD under the action of temperature distortion in the environment during fire is based on the realization of a non-stationary dynamic correction of the output signal from a thermal sensor in MTFD. A non-stationary dynamic correction of the output signal is carried out by using an inertial-forced link with a transfer function. Time constant of the inertial part of this link is changed by time in the interval of temperature measurement. We proposed a rule for changing the time constant of inertial part of the inertial-forced link to correct the output signal from a sensor in MTFD. This rule allows us to propose a method for improving the performance speed of MTFD with a simultaneous reduction in fluctuations of the output signal in the correction link.

3. We ran comparative analysis of the known and the new methods to enhance the performance speed of MTFD under the action of considerable temperature perturbation in the environment during fire. The analysis conducted demonstrated that according to the known method, improvement in the performance of MTFD is possible only by increasing fluctuations in the output signal as well as the number of false triggering. In this case, according to the proposed method and the rule of change in time constant

of a correction link, as evidenced by the obtained data of modeling, there happens an improvement in performance of a fire detector without increasing the fluctuations of output signal. It was established that an increase in the performance speed of detector relative to mathematical expectation and dispersion in fluctuations of the output signal occurs at different moments of time. This time is much less than the time for actuating the existing MTFD (20 s). For example, according to data in Fig. 4, performance improvement relative to the mathematical expectation of the output signal is larger than by 5 times. In this case, relative to the dispersion in fluctuations of the output signal – by 1.5 times.

Thus, the new method for improving the performance of MTFD under the action of significant temperature perturbation has benefits over the known one. The method proposed is recommended for the implementation to improvement the performance speed of existing MTFD when employing them under severe conditions. Such conditions are characteristic primarily of the industrial enterprises and facilities in metallurgy, oil and gas sector, for the purpose of their effective fire protection.

References

1. Poulsen, A. Experimental Study on the Burning Behavior of Pool Fires in Rooms with Different Wall Linings [Text] / A. Poulsen, G. Jomaas // Fire Technology. – 2011. – Vol. 48, Issue 2. – P. 419–439. doi: 10.1007/s10694-011-0230-0
2. Oppelt, U. Improvement on fire detectors by using multiple sensors [Electronic resource] / U. Oppelt // Fire & Safety. – 2006. – Available at: http://www.securitysa.com/regular.aspx?pklregularid=2502
3. Pospelov, B. B. Uchet priemlemogo riska pri obosnovanii trebovanij k sistemam kontrolja sostojanija opasnyh ob'ektov [Text] / B. B. Pospelov, S. N. Chumachenko, I. V. Uriadnikova // Aktual'ni problemy modeljuvannja ryzykiv i zagroz vynyknennja nadzvychajnyh sytuacij na ob'jektah krytychnoi' infrastruktury. – Kyiv: TOV «Instytut matematychnogo modeljuvannja «Fraksim», 2015. – P. 139–145.
4. Ding, Q. Multi-Sensor Building Fire Alarm System with Information Fusion Technology Based on D-S Evidence Theory [Text] / Q. Ding, Z. Peng, T. Liu, Q. Tong // Algorithms. – 2014. – Vol. 7, Issue 4. – P. 523–537. doi: 10.3390/a7040523
5. Cheng, C. One Fire Detection Method Using Neural Networks [Text] / C. Cheng, F. Sun, X. Zhou // Tsinghua Science and Technology. – 2011. – Vol. 16, Issue 1. – P. 31–35. doi: 10.1016/s1007-0214(11)70005-0
6. Pospelov, B. B. Improving Efficiency Monitoring Systems for Potentially Dangerous Objects Based on Optimization of Group Detection Sensors [Text] / B. B. Pospelov, V. A. Andronov // Civil Engineering and Architecture. – 2015. – Vol. 3, Issue 4. – P. 69–72. doi: 10.13189/cea.2015.030401
7. Pospelov, B. B. Sintez optimal'nogo izmeritelja opasnyh faktorov pozhara s proizvol'noj dinamikoj dlja pozharnyh izveshhatelej [Text] / B. B. Pospelov, R. I. Shevchenko, A. N. Kolenov // Problemy pozharnoj bezopasnosti. – 2014. – Issue 35. – P. 172–178.
8. Siebel, R. Test of Fire Detection Algorithms using Artificially Generated Events [Text] / R. Siebel // Fire Safety Journal. – 2006. – Vol. 41, Issue 4. – P. 258–265. doi: 10.1016/j.firesaf.2006.01.004
9. Gurevich, V. Microprocessor protection devices: The present and the future [Text] / V. Gurevich // Serbian Journal of Electrical Engineering. – 2008. – Vol. 5, Issue 2. – P. 325–339. doi: 10.2298/sjee0802325g
10. Radonja, P. Generalized Profile Function Model Based on Neural Networks [Text] / P. Radonja, S. Stankovic // Serbian Journal of Electrical Engineering. – 2009. – Vol. 6, Issue 2. – P. 285–298. doi: 10.2298/sjee0902285r
11. Tsai, Y. C. The Design and Implementation of Early Fire Detection and Hierarchical Evacuation Alarm System, Master Thesis [Text] / Y. C. Tsai // Graduate Institute of Networking and Communication Engineering. – Taiwan, 2007.
12. Jovan, D. Decision Algorithms in Fire Detection Systems [Text] / D. Jovan, B. Dragana // Serbian Journal of Electrical Engineering. – 2011. – Vol. 8, Issue 2. – P. 155–161. doi: 10.2298/sjee1102155r
13. Willstrand, O. Detection of fires in the toilet compartment and driver sleeping compartment of buses and coaches – Installation considerations based on full scale tests [Text] / O. Willstrand, J. Brandt, R. Svensson // Case Studies in Fire Safety. – 2016. – Vol. 5. – P. 1–10. doi: 10.1016/j.csfs.2015.11.002
14. Zheng, W. Experiment Study of Performances of Fire Detection and Fire Extinguishing Systems in a Subway Train [Text] / W. Zheng, X. Zhang, Z. Wang // Procedia Engineering. – 2016. – Vol. 135. – P. 393–402. doi: 10.1016/j.proeng.2016.01.147
15. Pat. No. 81975 UA. Maksymalno-dyferentsiinyi teplovyi pozhezhnyi spovishchuvach. MPK G08B17/06 [Text] / Abramov Iu. A., Sadkovyi V. P.; vlasnyk Akademiia tsyvilnoho zakhystu Ukrainy. – No. 200603837; declareted: 7.04.2006; published: 17.07.2006, Bul. No. 4.