CURRENT STATE OF RESEARCH AND NORMATIVE FRAMEWORK REGARDING ASSESSMENT OF FIRE ALARM SYSTEMS SUITABILITY FOR OPERATION

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Abstract: Regardless of how reliable modern fire alarm systems are against false alarms, a significant number of fire alarms cannot be relied upon due to the undesirable sensitivity of fire detectors. One of the most important characteristics of the reliable operation of the fire alarm system is the accuracy and reproducibility of the activation of fire detectors under the influence of dangerous fire factors. Namely the achievement of the accuracy of measuring the magnitude of the signal at which the fire alarm is triggered during external testing we have taken as the basis, as a working hypothesis, for soling the main task - increasing the operability of the fire alarm system. The above implies the need to implement a set of measures aimed at maintaining these systems in good technical condition, which ensures their use for their intended purpose. The work reveals the innovative approaches of domestic Ukrainian and foreign researchers in maintaining fire alarm systems in a suitable operating condition and rationalizing the methodology for diagnosing the sensitivity of fire detectors to the controlled parameters of the service area. The research makes it possible to build a solid foundation for identifying gaps in the methods of diagnosing fire alarm systems, deriving ideas that contribute to the development of new conceptual foundations of the subject area.

Keywords: fire alarm system; fire detector; tester; operability; reliability; diagnostics.

1 Introduction

According to statistical data, more than 390,000 economic facilities in Ukraine are equipped with fire alarm systems, which is 93.7% of their required number. It is known that 14.4% of object fire alarm systems have exhausted their resource, are morally obsolete and need to be replaced. Generalized statistical data also indicate that over the past five years in Ukraine, fires have occurred at more than 1,600 facilities where a fire alarm system was installed. In 62.5% of cases, fire alarm systems provided timely notification of the occurrence of a fire. In the rest of the cases, its failure contributed to an increase in the risk to people's lives and an increase in the probability of material damage caused by fire at these facilities [11].

Scientist M. Ahrens [1] provides information on the death rate of people due to fires in residential buildings with a working fire alarm system using smoke fire detectors, which is 54% lower than in those where it is in a non-working state or is absent (Figure 1). There is evidence that every percentage point of installation of fire alarm systems reduces the number of registered fires by more than 2.6%.

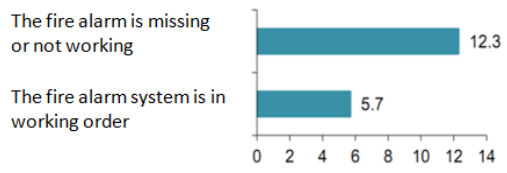

Figure 1. The rate of deaths per 1,000 registered fires in residential buildings equipped with fire alarms using smoke detectors [1]

At the same time, a significant number of fire alarm signals from fire alarm systems are not reliable. Scientists confirm that the level of false signals generated by the fire alarm system without existing fire-related signs is 22% of the total number of all its activations [17]. Researchers from Poland provide data that 35% of false alarms in fire alarm systems are associated with malfunctioning fire detectors [24]. Scientist A. Hangauer claims that the number of false alarms can reach 50% of all fire alarms due to the unwanted cross-sensitivity of fire detectors to particles of substances that are not necessarily formed as a result of a fire (water vapor, dust, insects or even hairspray, etc.) [16]. And this is despite the fact that modern fire detectors are highly reliable and resistant to false alarms.

False fire alarms represent a serious problem for both facility managers (who must analyze the causes of occurrence and take measures to reduce them) and emergency services (who must deploy certain resources to respond). Experts from the Hochiki company (Japan), which has been a leader in the development and production of innovative products in the field of fire safety for more than a hundred years, found that the costs of false fire alarms, for example in the UK, constitute approximately 700 million pounds every year. They explain that nine out of ten false alarms of the fire alarm system led to the complete evacuation of people from buildings or other structures with a loss of labor productivity. But the problem appears to be deeper, as 56% of business owners surveyed said that too many of these triggers mean employees don not take real anxiety seriously. They develop fatigue and complacency, which can lead to unpredictable consequences [10].

The rapid development of technology, market requirements and wear and tear during the operation of the fire alarm system lead to the need for frequent maintenance, repair or replacement of individual components. Countries such as the USA, Canada, Australia, Singapore, Germany, Sweden, Norway, Denmark are known for their high quality of service and timely updating of fire alarm systems, and have strict standards requirements for their compliance. It is believed that the level of maintenance of fire alarm systems depends on the qualifications and professional training of personnel, the presence of regulatory requirements for the regulation of maintenance issues, the general approach to safety, etc. Service companies in these countries, which are distinguished by the professionalism of their specialists, usually meet the specified requirements.

Properly designed and installed fire alarm systems must ensure that a fire is quickly detected and an alarm signal is issued for the necessary measures to be taken. The requirements determined by the norms of the national standard provide for the need to maintain fire alarm systems in working condition, taking into account the average working time of the fire alarm upon failure [7, 8].

The purpose of this work is to conduct an analysis of the current state of research and the regulatory framework for assessing the operability of fire alarm systems.

The object of research is the processes of maintaining the operational suitability of fire protection systems.

The subject of the study is literary sources and the regulatory framework for assessing the operability of fire alarm systems.

2 Materials and Methods

The research uses theoretical analysis and synthesis to study existing and form new approaches to solving the problem of maintaining the fire alarm system in a serviceable condition and rationalizing the methods of diagnosing the sensitivity indicators of fire detectors. The work also used other scientific research methods (logical analysis, statistical, etc.).

3 Results and Discussion

Taking into account the fire risk and the efficiency of fire alarm systems, the one that provides detection and notification of dangerous fire factors with the expected high sensitivity is

considered reliable. It is known that the standards in force in Ukraine do not provide data on the reliability parameters of the fire alarm system. However, there is confidence that a fire alarm system that consists of equally reliable components, designed by qualified professionals, obtained from a competent supplier and tested by an experienced specialist will work properly. These explanations are not a warning, but rather key elements in ensuring the operability of the fire alarm system.

Proper organization of technological processes, standardization, and other factors increase the reliability of components used in fire alarm systems, reducing the level of their failures [3]. The combination of the achieved level of reliability, as a complex property of the fire alarm system to perform the specified functions, with the preservation of its main characteristics within the established limits, with the requirements and recommendations of the regulatory documents in force in Ukraine, is a compromise that must be monitored by the state market surveillance body in this field.

Researchers characterize the functionality of fire alarm systems in sufficient details, describe the operation of devices and engineering tools depending on simulated fire scenarios [25]. In the created model of a typical fire alarm system, taking into account the analysis of the development of the fire, with the help of the ANASYS software, its optimal functioning parameters are determined. Thematic studies by the scientist L. Keding show that when the response time of the fire alarm system is reduced to five seconds, it is capable of ensuring the effective evacuation of people from a high-rise building [22].

Scientist L. Qiang notes that one of the important elements of designing fire alarm systems is the calculation of fire detection time. His work presents a method of fire detection by thermal and smoke fire detectors by time [30]. The publication of J. Paś and T. Klimczak contains research on the methodology of testing fire alarm systems at transport facilities [28]. The authors present the results of technological tests, taking into account which they build operational dependence, that makes it possible to specify the parameters of work and reliability when finding a fire alarm system in the studied states.

Research by M. Jafari, M. Pouyakian, and A. Khanteymoori is aimed at using Fault-Tree Analysis to determine the causes associated with failure of fire alarm systems, use of fuzzy set theory and expert detection to determine relative probabilities. The reliability of the fire alarm system using the dynamic Bayesian method (Bayesian networks) was evaluated over a period of 36 months. The results confirm the assumption that re-planning and carrying out repair work in the premises of a building or structure are the most important factors in the failure of the fire alarm system. The authors also prove that the reliability of such a system can be increased from a factor of 0.375 to 0.965 due to the implementation of preventive and control measures, which will reduce the probability of a critical event [19].

Scientists B. Forell, J. Peschke, and S. Einarsson built the event and failure tree for probabilistic fire safety analysis of the active zone of the nuclear power plant. The technical reliability of the fire alarm system was assessed by the intensity of failures [12]. Scientists S. Gupta, S. Kanwar, and M. Kashyap, investigating the reliability of the fire alarm system using Algebra of logic, compared individual indicators of the fire alarm system and the average the time between the occurrence of failures on a numerical example with two different service life distributions: Weibull and exponential. Such evaluation of the fire alarm system, according to the authors, is of crucial importance for ensuring the safety of critical objects [15].

The results of L. Gomez-Agustina's computer modeling of the quantitative influence of temperature and relative air humidity on the performance of the fire alarm system demonstrated an increase in the reverberation time values both under conditions of increased temperature and increased humidity of the controlled room on critical frequencies for speech intelligibility [13]. Scientist J. Paś justifies that the processes of aging and wear, exposure to dust, vapors, exposure to vibration, shocks, etc. cause changes in the main parameters of fire detectors and the speed of detection of dangerous fire factors, lead to false alarms and system failures of fire alarm system [29].

The use of a specific type of fire detectors depends on the object of protection, the likely scenario of fire development at such objects, regulatory requirements for the design of the fire alarm system, etc. As it is known, fire detectors are characterized by various technical indicators that are important for determining their quality: the minimum value of the controlled parameter (or its rate of change), at which the detector is triggered (trigger threshold); the time from the moment when the controlled fire parameter reaches the trigger threshold value of the sensitive element of the fire detector until the moment the fire signal is issued (trigger inertia); the controlled area on which one detector is installed (the maximum range of the detector), etc.

Table 1 shows selected technical characteristics, according to their passport data, of some of the fire detectors of fire alarm systems common in Ukraine. As can be seen from the table, the maximum static temperature of fire detectors is 85°C, the threshold of smoke fire detectors is usually up to 0.2 dB/m, and the inertia of fire detectors is up to 5 s, up to 10 s, and up to 30 s.

Table 1: Technical characteristics of fire detectors

The name of the fire alarm	Static operating temperature (°C)	Inertia of activation (s)	Sensitivity (trigger threshold) (dB/m)	Sensitivity of the gas sensor	Emission wavelength range (nm)	Service life (year)
Smokey						
СП-2.2	+54 to +70	No more than 15	0.05 - 0.2	-	-	10
ИПК-8	+56 to +70	No more than 5	0.05 - 0.2	-	-	10
СПД-3.10	+54 to +70	No more than 10	0.05 – 0.2	-	-	10
Thermal						
TIRAS СПТ-А	class A1: +54-65 class A2: +54-70 class B: +69-85	No more than 5	0.05-0.2	-	-	10
ІІІ 101-34-А1	+50 to +54	No more than 10	0.05 - 0.2	-	-	10
FTL-BS Arton	+69 to +85	No more than 10	9 - 30	-	-	10
Flame						
СПП Алмаз	+55	No more than 5	-	-	UV: 220-280	5
СПППА-В	+55	No more than 30	-	-	IR: 4150-4550	3.5
Combined						
ATD 3-15	+65±0.5	No more than 10	0.05-0.2	-	-	7
ИП 212/101-2-А1R	+58	No more than 10	0.12	-	-	10
FCP-OC320	+54 to +70	No more than 10	0.16-0.25	In the range, ppm (1 mg/kg)	-	5

Scientists S. Bondarenko and J. Paś are of the opinion that fire alarm systems provide the necessary level of sensitivity of fire detectors at the initial stage of operation. Over time, the technical parameters of fire detectors are less controlled, the probability of damage to the fire alarm system increases due to internal processes occurring at the facility, the lack of necessary conditions and equipment both at the business entity and at the installation organizations [4; 29]. Therefore, any changes in the sensitivity parameters of fire detectors during the operational period (periodic, random, of different sizes and values) reveal a certain dependence on the time of operation [23].

Scientists believe that practically a fire alarm system can be in only two states: in a serviceable state (when it maintains its performance within the established limits) or in an unusable state (when it cannot be used for its functional purpose) [1; 29]. There is also the opinion of scientists that the fire alarm system can be in an operational state, in a state of probable risk of damage, and in a state of failure [20]. Considering the requirements of DSTU CEN/TS 54-14:2021, due to the aging and wear of the fire alarm

system components and the influence of other possible factors that reduce the sensitivity of fire detectors, there is a state that fills the space between the operational and unusable states. Such, in our opinion, is the state of "inappropriate functioning" of the fire alarm system, it is a state in which the components of the fire alarm system cannot maintain their basic parameters within the established limits. So, for example, the trigger threshold or inertia of the fire detectors of the fire alarm system do not meet the defined parameters.

Figure 2 shows the probabilistic characteristics of the fire detector being in working and non-working states, depending on the sensitivity value and the time of operation. In the state when the fire detector maintains its sensitivity value, given the regulatory requirements [7; 8; 9] and the requirements of operational documentation, is within the operating time from t_0 to t_1. At the same time, the sensitivity threshold value of the fire detector meets the manufacturer's and design requirements (from 1 to P_1).

The probable reduction of the sensitivity limit of the fire detector (from P_1 to P_2) does not imply reliable operation of the fire alarm system during the period of operation time t_1-t_2. Due to the reduction of the sensitivity limit, it is not recommended to use the fire alarm as intended during this period. Changes in the parameters of fire detectors, caused by various processes, create significant difficulties in assessing the suitability of the fire alarm system for operation.

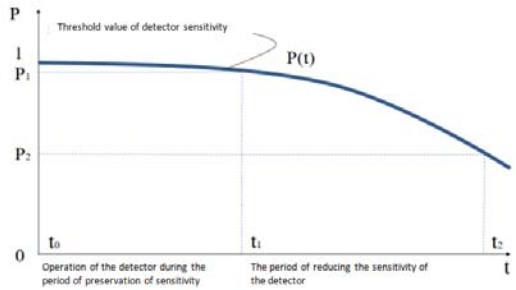

Figure 2. Probability of the fire alarm being in working and inappropriate states

The practice of using fire alarm systems confirms the thesis that the level of sensitivity of fire detectors can decrease over time due to the aging of its individual components, the influence of dust and vapors, exhaust gases from engines, and other factors, which over time leads to a failure in the reliability of their functions. This condition can occur if the performance check, maintenance of the fire alarm system components in accordance with the regulations and operational documentation of the manufacturer is not carried out or is carried out not in a timely manner and with poor quality.

Since the fire alarm system must work reliably and without fail in the event of a fire, as well as under the influence of conditions that may occur during operation, the business entity must ensure the elimination of the reasons for its inappropriate condition. Otherwise, over time (more than t_2), the fire alarm system will cease to be operational due to insufficient sensitivity of the fire detector (from P_2 to 0). The return of the fire alarm system from a state of non-compliance to an operational state is carried out starting from: identification of such a state; conducting timely and high-quality maintenance; performance of repair and restoration works or technical re-equipment, taking into account the average time of operation of fire detectors for failure; inspection/testing, adjustment and restoration of the operational characteristics of the fire alarm system and its individual components in accordance with the design ones.

Researchers demonstrate different approaches to solving the task of improving the methods of preventive diagnostics of fire detectors, and together with specialists in the field of fire protection, continue to develop means of their testing. Depending on the specifics of the application, such devices have a heater or heater-evaporator, a heat generation system (smoke, CO), manual or electronic control. Scientist F. Joglar focuses on the need to maintain the operability of fire alarm systems, which is implemented by optimizing diagnosis periods, calculating probability values for fire hazard assessment [21]. S. Ross, S. Nowlen, and T. Tanaka [32] place emphasis on the importance of preventive diagnostics, which significantly reduces the risk of failure of components of the fire alarm system at the nuclear power plant.

The trend of scientific and technical achievements of fire alarm systems and means for their verification can be found in patent documents, from which it is possible to obtain up to 80% of the necessary information. The main achievements of the patent holders from Ukraine are: the development of means of performance monitoring without the use of external heat sources in a completely autonomous mode; ensuring control of the dynamic parameters of the fire detector; determination of the alarm activation time; increasing the reliability of thermal fire detectors; increasing the reliability of fire detection by increasing the level of automation, etc. [33].

In the patent funds of the countries of the world, there is a dependence between the number of technical solutions for diagnosing fire detectors and the number of technical solutions for their respective types. Scientists cite the ratio between the number of heat, smoke, and light detectors patented in the world, which is 20%, 66%, and 14%, respectively, and the ratio of various technical means for their verification - 32%, 56%, and 12% [6]. A patent search in the Google Patents database [14] using the keywords "Fire detector test device" made it possible to identify about six thousand results, which can potentially be considered for the purpose of assigning to the operability of fire alarm systems.

A search of patent documents under the subclass "G08B0029140000 Inspection of detection chains" of the class "G08B0017000000 Fire alarm" in the information and search system of patent research of the international patent classification (MPK-2024.01) revealed a method of checking fire detectors with a manual device [18; 26]. The specified device creates a simulated alarm condition to verify whether the fire alarm will trigger. In its first compartment, there is an adjustable heat source that heats the closed air mass at a controlled rate. The second compartment contains an electronic circuit for regulating the temperature level and heating speed of the heat source. The operational efficiency of the fire alarm system is indicated by the activation of the detector during the specified time interval after supplying the heated air mass.

Inventions [2; 27] involve testing fire detectors using a tester guided by a navigation control device of an unmanned vehicle. In the patent [34], a method of preventing false activation of the fire alarm system when changing the sensitivity threshold of fire detectors is proposed. Responding to the detection of a future false alarm, the fire alarm control system issues an audible or visual warning of a predetermined period of time before the change of the future sensitivity threshold of the fire detector.

Despite a significant amount of scientific research and development, we have not found information that would relate to methods of diagnosing the accuracy of measuring the actual value of the sensitivity of fire detectors using a tester aimed at maintaining the fire alarm system in a serviceable condition. No test device determines the degree of compliance of a fire detector with certain parameters, the technical aging of fire detectors is not taken into account during the test.

Generalized technical characteristics of existing testers enable identification and analysis of issues related to the reliability of the process of evaluating fire alarm systems. The data of the technical characteristics of devices for testing fire detectors given in Table 2 show that the maximum set temperature in devices for testing fire detectors is up to 100°C. For testing smoke detectors, the control parameter, as a rule, is not implemented in existing devices.

Taking into account the technical characteristics of fire detectors, we conclude that the device for their testing must implement a temperature range from 50°C to 100°C ± 10°C. At the same time, the specified device must be able to record the inertia of the fire alarm. For the smoke test, the criterion should be the optical density of smoke (dB) using optical attenuators (filters) [31].

Table 2: Technical characteristics of devices for testing point fire detectors

Name of the device	Application of detector (by type of controlled environment)	Settable temperature range (°C)	Aerosol (name, volume)	Height (range) testing (m)
Solo 330 aerosol tester (sprayer simulator)	smoke	-	An aerosol can Solo A3 (250 ml)	Up to 9
Smoke Saber handheld tester	smoke	-	An aerosol can with imitation of smoke (150ml)	0.22
Aerosol tester (sprayer) FireWolf	smoke	-	Prufgas 918/5 aerosol can (250 ml)	Up to 4
A set of test devices KTP-1	smoke	-	An aerosol can with imitation of smoke	Up to 4
	thermal	50-100	-	
Tester (simulator) TESTIFIRE	smoke	-	Cartridge-capsule with smoke simulator TS3	Up to 9
	thermal	90-100	-	
	CO	-	Cartridge-capsule TS3 with CO	
Tester SOLO 461	thermal	90	-	Up to 5
Test simulator FS	flame	IR/UV, depending on the sensitivity of the detectors	-	Up to 12

Therefore, fire alarm systems have different types and functional structures, while the reliability of their individual components is not the same, as evidenced by the analytical review of domestic Ukrainian and foreign literature, patent information, and existing regulatory documents. In many developed countries of the world, the level of service of fire alarm systems is assessed: by the qualifications of the personnel of service companies; the presence of regulatory requirements regulating the issue of their preparation and performance of works; general approach to fire safety, etc. At the same time, one of the most important characteristics of the reliable operation of the fire alarm system is the accuracy of the activation of fire detectors under the influence of dangerous fire factors. The priority research of scientists is to reduce the accuracy error of the fire detector of the fire alarm system, to enable the minimization of false fire alarms.

But the issue of creating a modern method that allows to quantitatively assess the operational condition and suitability of fire alarm systems, taking into account the most significant parameters, which can be used to determine the functional suitability of such systems, remained neglected.

Therefore, in the future, research aimed at identifying patterns of changes in the parameters of fire detectors depending on the conditions of their operation is an urgent task. The above is the basis for assessing the technical condition of fire alarm systems as a scientific basis for establishing their operational suitability. The implementation of the above will allow taking into account the most significant factors when evaluating the operational suitability of fire alarm systems, while achieving the maximum level of fire safety and economic effect.

In order to achieve the set goal, it is expected to solve the following scientific problems:

- To analyze the current state of research and the regulatory framework for assessing the suitability of fire alarm systems for operation;
- To justify the criterion base characterizing the processes of response of fire detectors to dangerous factors of fire, as well as the provisions for ensuring operational condition;
- To develop methods of experimental studies of the processes of reaction of fire detectors to the parameters of dangerous fire factors;
- To conduct experimental studies according to the developed methods and, based on the obtained experimental data, build regression models of the characteristics of fire detectors and their operating conditions;
- Comparing the results of experimental studies with the data of theoretical studies obtained on the basis of developed mathematical models, prove their adequacy, assess accuracy;
- Using the developed mathematical models, to conduct a numerical experiment on assessing the suitability of fire alarm systems for operation;
- On the basis of the developed laws, develop methodical support for evaluating the suitability of fire alarm systems for operation;
- To investigate the economic efficiency of the developed methodological support for evaluating the suitability of fire alarm systems for operation.

The object of the research will be the processes of response of fire detectors to the parameters of dangerous fire factors, as well as the conditions for ensuring their operational suitability. The subject of the study will be the relationship between the characteristics of fire detectors and the parameters of dangerous fire factors and the conditions suitable for their operation.

4 Conclusion

It is established that the maximum static temperature of fire detectors is 85°C, the threshold of smoke fire detectors is usually up to 0.2 dB/m, and the inertia of fire detectors is up to 5 s, up to 10 s and up to 30 s. The maximum set temperature in devices when testing fire detectors is up to 100°C. To assess the suitability of smoke detectors, the control parameter is usually not implemented in existing devices. Thus, the device for testing fire detectors should implement the temperature range from 50°C to 100°C ± 10°C. At the same time, the specified device must be capable of recording the inertia of the fire alarm. To test fire detectors for smoke, the criterion should be the optical density of smoke (in dB) using optical attenuators (filters).

The work proved that, in addition to operational and unusable ones, there is a state of inappropriate functioning of the fire alarm system, in which its components cannot maintain their main parameters within the established limits, which leads to a threat to safety in the controlled area. Thus, the purpose, scientific tasks, object and subject for future scientific research are substantiated.

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Primary Paper Section: J

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