UDC 681.5.075
DOI: 10.15587/1729-4061.2022.266825

DEVELOPING A METHOD FOR DETERMINING THE TIME PARAMETERS OF A MOBILE FIRE EXTINGUISHER OPERATOR

The object of this study is the process of functioning of the "man-machine" system on the example of the operator of a mobile fire installation. One of the issue when building models of such systems is to determine the parameters a priori of a given model of the human operator – the delay time and a time constant.

For one of the promising means of fire extinguishing such as a mobile installation based on Segway, a method for determining the time parameters of the operator has been devised. A feature of the method is the use of approximation of partial derivatives from the phase-frequency characteristics of the operator in frequency, determined at two frequencies. This approach makes it possible to get rid of the need to use transcendental equations to determine time parameters and move on to an algebraic equation. To substantiate the values of frequencies at which partial derivatives are approximated, tolerance accuracy criteria are used. It is shown that working range of the operator of the mobile fire installation is in the infra-frequency region. Therefore, it is advisable to determine the phase-frequency characteristics of the operator numerically using an array of data on the transition function of the operator. An array of such data is formed using the Kotelnikov-Nyquist-Shannon theorem. A list of sequential procedures for the implementation of the method for determining the time parameters of the operator of a mobile fire installation is provided. The method for determining the time parameters of the operator of a mobile fire installation was verified by solving a test problem. It is shown that with permissible errors in the time parameters of the operator at the level of 5.0 %, the errors in their determining do not exceed 2.0 %.

The reported results can be used for determining the dynamic parameters of the model of the operator of the fire installation, provided that the tolerance criterion for accuracy is set

Keywords: mobile fire installation, operator, time parameters, dynamic parameters, frequency characteristics

Yuriy Abramov
Doctor of Technical Sciences, Professor, Chief Researcher
Research Center**
Oleksii Basmanov
Corresponding author
Doctor of Technical Sciences, Professor, Chief Researcher
Scientific Department of Problems of Civil Defense,
Technogenic and Ecological Safety of Research Center**
E-mail: oleksii.basmanov@nuczu.edu.ua
Vitaliy Sobyna
PhD, Associate Professor, Head of Department*
Dmitry Sokolov
PhD, Associate Professor*
Serhii Rahimov
PhD, Associate Professor*
*Department of Organization and Technical Support
of Emergency Rescue Works**
**National University of Civil Defence of Ukraine
Chernishevska str., 94, Kharkiv, Ukraine, 61023

Received date 22.09.2022
Accepted date 25.11.2022
Published date 30.12.2022

***How to Cite**: Abramov, Y., Basmanov, O., Sobyna, V., Sokolov, D., Rahimov. S. (2022). Developing a method for determining the time parameters of a mobile fire extinguisher operator. Eastern-European Journal of Enterprise Technologies, 6 (2 (120)), 93–99. doi: https://doi.org/10.15587/1729-4061.2022.266825*

1. Introduction

Among the means of fire extinguishing, an important place is occupied by vehicles. For example, the decisive role in extinguishing a fire in the Cathedral of Notre Dame (April 2019) was played by the mobile installation "Colossus" designed by Shark Robotics (France) [1]. In 2018, a fire drone was successfully tested in Latvia, which can extinguish fires at an altitude of 300 m [2]. A promising means of fire extinguishing is a mobile fire installation based on Segway [3]. Management of such a mobile fire installation both under a patrol mode and in the fire extinguishing mode is carried out by the operator. For the most efficient use of mobile fire installations, their characteristics must be coordinated with the characteristics of the operator [4]. In this regard, there is a need to build mathematical models of operators of such mobile fire installations or to identify the parameters of such models with their a priori known structure. In addition, when operating mobile fire installations, there is a need to test the operators of these systems. In this case, information on the parameters and characteristics of operators can be used. Such parameters include, in particular, time parameters – the time of delay and the time constant of the operator of the mobile fire installation. Thus, the task of determining the parameters a priori for a given mathematical model of the operator of a mobile fire installation is relevant.

2. Literature review and problem statement

With regard to the mathematical description of human operator activity, it should be noted that there is a tendency to take into account various factors. So, for example, in [5] it is noted that the human operator plays a very important role, especially in the event of an emergency in industrial production. There is a need to work on such emergencies and related problems for the operator. However, there is no information in the cited work regarding models that reflect the behavior of the operator in such situations. This type of research also includes paper [6], which declares the need for "accurate determining of human behavior" when it is included in the automated system. This requires objective indicators that flow from the corresponding mathematical models. Such models are not given in the cited work. It is not clear what the author means when the term "reliable human-operator models" is used. The study does not provide an indicator of the reliability of the model. It should be noted that most of the developed models do not take into account such factors as experience, load, etc. [7], which is associated with the individual characteristics of the human operator. One of the ways out of this situation is to use integral indicators in human operator models. In particular, in [8] attention is paid to the fact that with an increase in the number of experiments there is a decrease in the values of the dynamic parameters of the operator of the fire installation. However, in the cited work there is no formalized description of this trend. The authors of [9] note that man and robot can perform only tasks that involve physical interaction. The concept of physical interaction between man and robot (pHRI) requires new approaches for its mathematical support and technical implementation. Thus, within the framework of this concept, work [10] reports the development of controllers, the use of which "softens" working conditions of a person when performing tasks of the corresponding class. The mathematical support of human activity in this case is reduced to a trivial level. Paper [11] reports the results of research on human–robot interaction using appropriate gestures. The method of controlling a wheeled robot using human operator gestures is given in [12]. This approach has been worked out on the mobile robot E-puck (Switzerland). These works apply the same approach, which boils down to the implementation of appropriate algorithms that use information from primary sensors – accelerometers and gyroscopes. Mathematical models of the human operator in the traditional sense within the framework of the concept of human-robot interaction are not used. The authors of work [13] point to the need for constant monitoring of the state of the human operator, due to the maintenance at the appropriate level of the effectiveness of the functioning of the cyberphysical system. An approach to the formation of a human-operator model is provided, which is based on the concept of a hierarchical representation of the virtual model of a complex system and the synergistic method of basic functions. However, this approach determines the complexity of the human-operator model and the constant adjustment of its parameters. To determine the characteristics of the human operator, imitators of the technological process are used [14], as well as "man in the circuit" simulators [15]. As a rule, with this approach, the characteristics of the human operator are determined, which reflect his integral properties. In [16], based on the virtual reality methodology, estimates of such operator parameters as the response time to an emergency and the time of the task execution were obtained. However, this procedure does not make it possible to determine such individual parameters of the operator as the time of delay and the time constant. The author of work [17] studied the process of adaptation of the human operator to perform typical tasks of the control system. A time parameter such as the time of delay of the human operator was set a priori while the algorithm for its control was absent. It should be noted that the emergence of new technical solutions in the construction of automated control systems requires the creation of new models, or the correction of existing models of the human operator. In particular, this concerns the emergence of a new class of mobile fire installations on the basis of Segways [18], which are controlled by the operator. It should be emphasized that the dynamic properties of such an operator fully determine its time parameters – the delay time and the time constant.

All this gives reason to argue that it is expedient to conduct a study aimed at building a method for determining operator parameters, in particular, time parameters, which include the delay time and the operator's time constant.

3. The aim and objectives of the study

The aim of our work is to build a method for determining the time parameters of the operator of a mobile fire installation, which characterize its lateness and inertial properties. This will make it possible to coordinate the characteristics of the mobile fire installation with the capabilities of the human operator.

To accomplish the aim, the following tasks have been set:

– to construct mathematical dependences for determining the time parameters of the operator;

– to justify the choice of parameters for mathematical dependences that are used in determining the time parameters of the operator;

– to compile a list of sequential procedures that enable determining the time parameters of the operator.

4. The study materials and methods

The object of this study is the process of functioning of the "man-machine" system on the example of a human operator and a mobile fire installation. The main hypothesis of the study assumes the possibility to determine the dynamic parameters of the model of the operator of a mobile fire installation using an array of data on the transition function of the operator. At the same time, to substantiate the values of frequencies at which partial derivatives are approximated, tolerance accuracy criteria are used.

The phase-frequency characteristics of the operator of a mobile fire installation are determined numerically on the basis of experimental data on its transient function. An array of experimental data is formed according to the Kotelnikov-Nyquist-Shannon theorem. Mathematical dependences for determining the time parameters of an operator are represented as a fourth-order algebraic equation. To find the roots of this algebraic equation, the Descartes-Euler, Ferrari methods, or the Maple application package (Canada) are used. The formation of initial data when substantiating mathematical dependences for determining the time parameters of an operator is carried out using mathematical analysis methods.

5. Results of research on the development of a method for determining the time parameters of the operator of a mobile fire installation

5. 1. Construction of mathematical dependences for determining the time parameters of the operator

The method for determining the time parameters of the operator of a mobile fire installation in the frequency domain is based on the use of its amplitude-frequency $A(\omega)$ and phase-frequency φ(ω) characteristics. These frequency characteristics are related through the complex transfer function $W(j\omega)$ of the mobile fire installation operator, i. e.

$$A(\omega)=\operatorname{abs}W(j\omega); \tag{1}$$

$$\phi(\omega)=\arg W(j\omega), \tag{2}$$

where ω is the circular frequency; j – imaginary unit.

If the complex transfer function of the mobile fire installation operator is described by the expression

$$W(j\omega)=K\exp(-j\omega\tau_0)(1+j\omega\tau_1)^{-1}, \tag{3}$$

where K – transmission coefficient; τ_0, τ_1 – time parameters, then taking into account the dependence

$$\exp(-j\omega\tau_0)=\cos\omega\tau_0-j\sin\omega\tau_0, \tag{4}$$

expression (3) is transformed as follows

$$W(j\omega)=M(\omega)+jN(\omega), \tag{5}$$

where

$$M(\omega)=K(\cos\omega\tau_0-\omega\tau_1\sin\omega\tau_0)\left[1+(\omega\tau_1)^2\right]^{-1}; \tag{6}$$

$$N(\omega)=-K(\omega\tau_1\cos\omega\tau_0+\sin\omega\tau_0)\left[1+(\omega\tau_1)^2\right]^{-1}. \tag{7}$$

This makes it possible to represent expressions (1) and (2) as

$$A(\omega)=\left[M^2(\omega)+N^2(\omega)\right]^{0,5}=K\left[1+(\omega\tau_1)^2\right]^{-0,5}; \tag{8}$$

$$\phi(\omega)=\operatorname{arctg}\left[N(\omega)M^{-1}(\omega)\right]=-\omega\tau_0-\operatorname{arctg}\omega\tau_1. \tag{9}$$

(8), (9) are the basis for devising a method for determining the time parameters of a mobile fire installation operator in the frequency domain. These time parameters fully characterize the dynamic properties of the operator of the mobile fire installation.

According to (9), for derivatives at frequencies ω_1 and ω_2, the following expressions hold

$$\frac{\partial\phi(\omega_1)}{\partial\omega}=-\tau_0-\tau_1\left[1+(\omega_1\tau_1)^2\right]^{-1}; \tag{10}$$

$$\frac{\partial\phi(\omega_2)}{\partial\omega}=-\tau_0-\tau_1\left[1+(\omega_2\tau_1)^2\right]^{-1}. \tag{11}$$

As a result, for the time parameter τ_0, two ratios can be written

$$\tau_0=-\left[1+(\omega_1\tau_1)^2\right]^{-1}\tau_1-\frac{\partial\phi(\omega_1)}{\partial\omega}=$$
$$=-\left[1+(\omega_2\tau_1)^2\right]^{-1}\tau_1-\frac{\partial\phi(\omega_2)}{\partial\omega}. \tag{12}$$

If we take into account that

$$\frac{\partial\phi(\omega_i)}{\partial\omega}=\lim_{\Delta\omega\to 0}\left[\left[\phi(\omega_i+\Delta\omega)-\phi(\omega_i)\right]\Delta\omega^{-1}\right]\approx$$
$$\approx\left[\phi(\omega_i+\Delta\omega)-\phi(\omega_i)\right]\Delta\omega^{-1}=A_i,\ i=1,2, \tag{13}$$

then, after combining expressions (12) and (13), the fourth-order algebraic equation with respect to the time parameter τ_1 is built

$$\omega_1\omega_2B\tau_1^4-\left(\omega_2^2-\omega_1^2\right)\tau_1^3+\left(\omega_1^2+\omega_2^2\right)B\tau_1^2+B=0, \tag{14}$$

where

$$B=A_2-A_1;\quad \omega_2>\omega_1. \tag{15}$$

To find the time parameter τ_1, which is the root of algebraic equation (14), it is necessary to have information on the values of frequencies ω_1, ω_2, $\Delta\omega$ and the values of the phase-frequency characteristic of the operator at frequencies ω_1, ω_2 and $\omega_2+\Delta\omega$. Time parameter τ_0 is determined after finding the root of algebraic equation (14) using one of ratios (12) where expressions (13) are taken into account. To find the root of algebraic equation (14), the methods of Descartes-Euler, Ferrari, or the Maple application package can be used.

5. 2. Justification of the choice of parameters for mathematical dependences for determining the time parameters of the operator

To determine the magnitude of the frequencies ω_1 and ω_2, the ratio between the errors of the amplitude-frequency Δa and the phase-frequency $\Delta\varphi$ characteristics of the operator and the errors of the time parameters $\Delta\tau_0$ and $\Delta\tau_1$ were used. These ratios are in the form

$$\Delta a=\Delta AK^{-1}=\operatorname{abs}\left(\frac{\partial a(\omega)}{\partial\tau_1}\right)\Delta\tau_1; \tag{16}$$

$$\Delta\phi=\operatorname{abs}\left(\frac{\partial\phi(\omega)}{\partial\tau_0}\right)\Delta\tau_0+\operatorname{abs}\left(\frac{\partial\phi(\omega)}{\partial\tau_1}\right)\Delta\tau_1, \tag{17}$$

where ΔA is the absolute error of the amplitude-frequency characteristic of the operator; $a(\omega)=A(\omega)K^{-1}$ – the reduced amplitude-frequency characteristic of the operator.

According to (16), the expression for the relative error $\delta\tau_1$ of the time parameter τ_1 will be

$$\delta\tau_1=\Delta\tau_1\tau_1^{-1}=\left[1+(\omega\tau_1)^2\right]^{1.5}(\omega\tau_1)^{-2}\Delta a. \tag{18}$$

The relative error $\delta\tau_0$ in accordance with (17) can be represented as follows

$$\delta\tau_0=\Delta\tau_0\tau_0^{-1}=(\omega\tau_0)^{-1}\left[\Delta\phi-\omega\tau_1\left[1+(\omega\tau_1)^2\right]^{-1}\delta\tau_1\right]. \tag{19}$$

After merging (18) and (19), the last expression is transformed to the form

$$\delta\tau_0=(\omega\tau_0)^{-1}\left[\Delta\phi-\left[1+(\omega\tau_1)^2\right]^{0.5}(\omega\tau_1)^{-1}\Delta a\right], \tag{20}$$

for which it is necessary to fulfill the condition

$$\Delta\phi>\left[1+(\omega\tau_1)^2\right]^{0.5}(\omega\tau_1)^2\Delta a. \tag{21}$$

The equivalent of this condition is a condition

$$\omega > \left[\tau_1\left[\left(\Delta\phi\Delta a^{-1}\right)^2 - 1\right]^{0.5}\right]^{-1}, \qquad (22)$$

hence, the relationship between errors Δφ and Δ*a* of the frequency characteristics of the operator

$$\Delta\phi > \Delta a. \qquad (23)$$

The choice of the magnitude of the frequencies ω_1 and ω_2 is carried out according to the criteria

$$\delta\tau_0 \le \delta\tau_{0\,\max};\quad \delta\tau_1 \le \delta\tau_{1\,\max}, \qquad (24)$$

where $\delta\tau_{0\,\max}$, $\delta\tau_{1\,\max}$ are the valid values of relative errors of time parameters. At the same time, conditions (22) and (23) should be used, and their nominal values can be used as the values of the time parameters τ_0 and τ_1 that appear in expressions (18), (20), (21).

To determine the value of Δω, we use the expression for the relative methodical error δ, which is due to the approximation of derivatives according to expression (13). This error is described by the expression

$$\delta = \left[\phi(\omega+\Delta\omega) - \phi(\omega)\right]\left[\Delta\omega\frac{\partial\phi(\omega)}{\partial\omega}\right]^{-1} - 1 =$$
$$= \left[\tau_0 + \Delta\omega^{-1}\mathrm{arctg}\left[\Delta\omega\tau_1\left[\left[\begin{matrix}1+(\omega\tau_1)^2 + \\ +\Delta\omega\omega\tau_1^2\end{matrix}\right]\right]^{-1}\right]\right] \times$$
$$\times\left[\tau_0 + \tau_1\left[1+(\omega\tau_1)^2\right]^{-1}\right]^{-1} - 1. \qquad (25)$$

Fig. 1 shows the dependence abs δ=f(ω, Δω), which is constructed for typical values of time parameters τ_0=0.2 s and τ_1=0.3 s, obtained in [8].

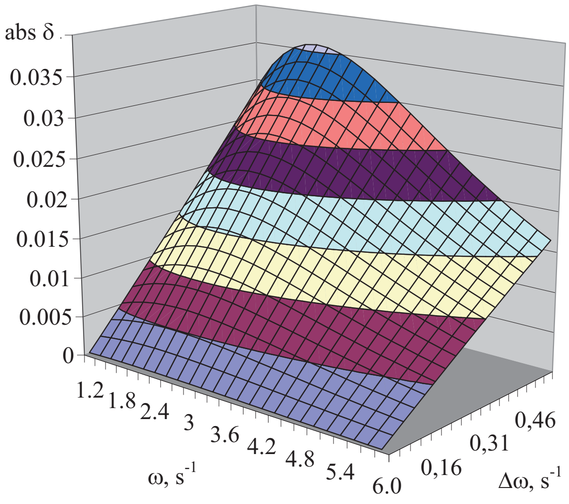

Fig. 1. Dependence abs δ=*f*(ω, Δω) at τ_0=0,2, τ_1=0,3 s

Fig. 2 shows a nomogram for determining the value of Δω, which is chosen by criterion

$$\mathrm{abs}\delta(\omega_1, \Delta\omega) \le \delta_{\max}, \qquad (26)$$

where $\delta_{\max}$ is the permissible value of the methodical error δ.

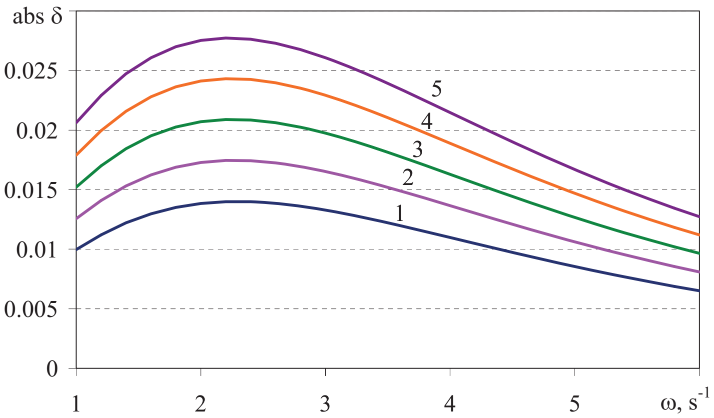

Fig. 2. Nomogram abs δ=f(ω) at Δω=const: 1 – Δω = 0,2 s^{-1}; 2 – Δω=0,25 s^{-1}; 3 – Δω=0,3 s^{-1}; 4 – Δω=0,35 s^{-1}; 5 – Δω=0,4 s^{-1}

Example 1. At Δ*a*=0.01 and Δφ=0.04, according to condition (22), ω_i>0.86 s^{-1} for τ_1=0.3 s. For $\delta\tau_{0\,\max}=\delta\tau_{1\,\max}$=5.0 %, according to expressions (18) and (20), we choose ω_1=2.0 s^{-1} and ω_2=3.0 s^{-1}. At $\delta_{\max}$=3.0 %, for ω_1=2.0 s^{-1}, according to Fig. 2, we choose Δω=0.2 s^{-1}.

5. 3. Development of a sequence of procedures that enable determining the time parameters of the operator

Determining the time parameters of the operator of a mobile fire installation is focused on the use of his frequency characteristics, as a result of which the question arises regarding their acquisition. At the same time, it should be noted that the operating frequency range for the operator of a mobile fire installation lies in the infra-low region and does not exceed (10.0÷12.0) s^{-1}.

Traditional methods for determining frequency characteristics are based on the use of sinusoidal signals, signals that approximate sinusoidal signals, or a field of harmonic signals. These methods have a number of disadvantages [19]:

– the complexity of equipment for measurements in the infra-low-frequency range;

– long measurement time;

– the need for signal conversion;

– measurement conditions and parameters of the object under study may change during measurements.

One of the options that is devoid of these shortcomings is the method of obtaining the frequency characteristics of the operator of a mobile fire installation, given in [20]. The method is based on the use of the transition function of the operator, which is determined experimentally at discrete moments of time with an interval Δ*t*, which is formed according to the Kotelnikov-Nyquist-Shannon theorem.

In this case, the phase-frequency characteristic of the operator of the mobile fire installation is described by the expression

$$\phi(\omega) = -\mathrm{arctg}\left[\begin{matrix}\left[\sum\limits_{k=0}^{n}\Delta_k\sin\left[\omega(k+0.5)\Delta t\right]\right]\times \\ \times\left[\left[\sum\limits_{k=0}^{n}\Delta_k\cos\left[\omega(k+0.5)\Delta t\right]\right]\right]^{-1}\end{matrix}\right], \qquad (27)$$

where Δ_k is the increment of the transition function of the operator on the time interval Δt between the k+1-*th* and k-th measurements.

To do this, devices can be used, the scheme of one of which is given in [21].

The implementation of the method for determining the time parameters of the operator of a mobile fire installation involves performing the following sequence of procedures:

– formation of requirements for the magnitudes of errors Δa and $\Delta\varphi$ of the frequency characteristics of the operator (taking into account condition (26));

– determining, according to expression (22), the lower limit for the frequency ω_1;

– formation of requirements for permissible values of relative errors $\delta\tau_{0\max}$ and $\delta\tau_{1\max}$ of the time parameters of the operator;

– determining frequencies ω_1 and ω_2 according to conditions (24) and using expressions (18) and (20);

– formation of requirements for the permissible value of the methodological error $\delta_{\max}$;

– determining the value of the frequency $\Delta\omega$ under condition (26) (using expression (25) or the nomogram shown in Fig. 2);

– determining parameters A_1, A_2 and B (according to expressions (13) and (15)) using data on the phase-frequency characteristic $\varphi(\omega)$ of the operator (according to expression (27));

– determining the value of the time parameter τ_1 as the root of algebraic equation (14), for example, using the Maple package;

– determining the value of the time parameter τ_0 using ratios (12) and (13);

– checking conditions (24).

Example 2. For data in example 1, it is obtained that A_1=–0,42 s, A_2=–0,36 s. According to (15), B=0.06 s. Algebraic equation (14) takes the form

$$0.36\tau_1^4-5.00\tau_1^3+0.76\tau_1^2+0.06=0,$$

one of the roots of which is τ_1=0.298 s.

According to expressions (12) and (13), τ_0=0.196 s. Errors in determining the time parameters τ_0 and τ_1 do not exceed 2.0 %.

6. Discussion of results of research on the development of a method for determining the time parameters of a mobile fire installation operator

The method for determining the time parameters of the operator of a mobile fire installation is based on the use of analytical dependences for his frequency characteristics. Unlike well-known methods, with the help of partial derivatives of the phase-frequency characteristic of the operator in frequency for two frequencies, a system of functions is built that includes time parameters. This system of functions acts as initial data in the formation of a mathematical justification of the method for determining the time parameters of the operator.

A feature of the activity of the operator of a mobile fire installation is that his operating frequency range lies in the infra-frequency region and does not exceed (10.0÷12.0) s^{-1}. This causes a number of technical difficulties in determining it, in particular, the phase-frequency characteristic. One of the features of the method is that when obtaining an expression for the phase-frequency characteristic of the operator (in the form of (27)), experimental data are used regarding the dynamic properties of the operator not in the frequency area but in the time domain. This makes it possible to simplify the procedure for determining the phase-frequency characteristics of the operator. Expression (27), obtained in this way, for the phase-frequency characteristic of the operator is used to construct an approximation (13) of the partial derivatives at two frequencies. The use of partial approximation of the phase-frequency function $\varphi(\omega)$ in frequency ω makes it possible to form analytical dependences to determine the time parameters of the operator. These dependences are in the form of a fourth-order algebraic equation (14) and relationships of the form (12). To use these dependences, it is necessary to have information regarding the magnitude of the frequencies ω_1, ω_2 and $\Delta\omega$. These frequency parameters are determined using tolerance criteria for accuracy. A feature of this is that the absolute value of the error of the phase-frequency characteristic of the operator must be greater than the absolute value of the reduced error of the amplitude-frequency characteristic of the operator. The relationship between the errors of the operator's frequency characteristics and the errors of its time parameters makes it possible to build analytical relationships between the frequency parameters ω_1 and ω_2 and these errors (expressions (18) to (20)). To determine the value of the frequency parameter $\Delta\omega$, expression (25) is used, which describes the methodical error in the approximation of partial derivatives. In the operational determination of the value of the parameter $\Delta\omega$, the nomogram shown in Fig. 2 can be applied.

The method for determining the time parameters of the mobile fire installation operator was verified using the test problem solution, which showed that the errors in determining all time parameters do not exceed 2.0 %.

The advantage of the developed method is that due to the use of partial derivatives of the phase-frequency characteristics of the operator in frequency, the simplification of the equation used in determining the time parameters is provided. In particular, when using the expression directly for the phase-frequency characteristic of the operator, such an equation is transcendental, in contrast to the algebraic equation in the form (14).

The limitation of the developed method for determining the time parameters of the operator of a mobile fire installation is the minimum possible values of errors in the amplitude-frequency and phase-frequency characteristics of the operator.

The caveat of this method is the presence of individual characteristics of the human operator, which makes it difficult to coordinate his characteristics with the characteristics of a mobile fire installation.

Further development of the method may be associated with its application to other dynamic models of operators of fire installations.

7. Conclusions

1. Mathematical dependences have been built to determine the time parameters of the operator of a mobile fire installation, which are based on approximations of partial derivatives of his phase-frequency characteristic over frequency at two a priori given frequencies, which are determined using the metrological characteristics of the operator.

2. Using the tolerance criterion for accuracy, the choice of frequencies is justified, and it is shown that the lower

limit of the values of these parameters is determined by the ratio between the errors of the phase-frequency and amplitude-frequency characteristics of the operator. Moreover, the lower limit of these frequencies is determined by the magnitude of the errors of the phase-frequency and amplitude-frequency characteristics of the operator, provided that the first exceeds the second.

3. A list of the sequence of procedures for determining the time parameters of the operator of a mobile fire installation has been developed, which involves the use as initial data of permissible values of relative errors for frequencies and for frequency characteristics of the operator. Using the solution to the test problem, the method for determining the time parameters of the operator of the mobile fire installation was verified and it was shown that the errors in determining them do not exceed 2.0 % with an allowable value of 5.0 %.

Conflicts of interests

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

Funding

The study was conducted without financial support.

Data availability

Manuscript has no associated data.

References

1. Paris Firefighters Used This Remote-Controlled Robot to Extinguish the Notre Dame Blaze. Available at: https://spectrum.ieee.org/colossus-the-firefighting-robot-that-helped-save-notre-dame#toggle-gdpr
2. Firefighter Drones – How Drones are Being Used for Helping Fire Departments. Available at: https://dronenodes.com/firefighter-drones/
3. Segway-like robots designed to help firefighters and save lives. Available at: https://newatlas.com/firefighting-robot-ffr/27849/
4. Villani, V., Czerniak, J. N., Sabattini, L., Mertens, A., Fantuzzi, C. (2019). Measurement and classification of human characteristics and capabilities during interaction tasks. Paladyn, Journal of Behavioral Robotics, 10 (1), 182–192. doi: https://doi.org/10.1515/pjbr-2019-0016
5. Müller, R., Oehm, L. (2018). Process industries versus discrete processing: how system characteristics affect operator tasks. Cognition, Technology & Work, 21 (2), 337–356. doi: https://doi.org/10.1007/s10111-018-0511-1
6. Kaber, D. B. (2017). Issues in Human–Automation Interaction Modeling: Presumptive Aspects of Frameworks of Types and Levels of Automation. Journal of Cognitive Engineering and Decision Making, 12 (1), 7–24. doi: https://doi.org/10.1177/1555343417737203
7. Kopyt, A., Dziewoński, T., Jastrzębski, D., Golon, K., Mirosław, M. (2017). Modeling of a human driver for a car driving simulator. ANSS '17: Proceedings of the 50th Annual Simulation Symposium. doi: https://doi.org/10.22360/springsim.2017.anss.005
8. Sobina, V., Hizhnyak, A., Abramov, Yu. (2019). Determination of parameters of the model of the operator of a mobile fire installation. Problemy pozharnoy bezopasnosti, 45, 161–166. Available at: https://nuczu.edu.ua/sciencearchive/ProblemsOfFireSafety/vol45/Sobina.pdf
9. Aydin, Y., Tokatli, O., Patoglu, V., Basdogan, C. (2018). Stable Physical Human-Robot Interaction Using Fractional Order Admittance Control. IEEE Transactions on Haptics, 11 (3), 464–475. doi: https://doi.org/10.1109/toh.2018.2810871
10. Yao, B., Zhou, Z., Wang, L., Xu, W., Liu, Q., Liu, A. (2018). Sensorless and adaptive admittance control of industrial robot in physical human-robot interaction. Robotics and Computer-Integrated Manufacturing, 51, 158–168. doi: https://doi.org/10.1016/j.rcim.2017.12.004
11. Tölgyessy, M., Dekan, M., Hubinský, P. (2018). Human-Robot Interaction Using Pointing Gestures. Proceedings of the 2nd International Symposium on Computer Science and Intelligent Control. doi: https://doi.org/10.1145/3284557.3284718
12. Nemec, D., Janota, A., Gregor, M., Hruboš, M., Pirník, R. (2017). Control of the mobile robot by hand movement measured by inertial sensors. Electrical Engineering, 99 (4), 1161–1168. doi: https://doi.org/10.1007/s00202-017-0614-3
13. Buldakova, T. I., Suyatinov, S. I. (2019). Hierarchy of Human Operator Models for Digital Twin. 2019 International Russian Automation Conference (RusAutoCon). doi: https://doi.org/10.1109/rusautocon.2019.8867602
14. Iqbal, M. U., Srinivasan, R. (2018). Simulator based performance metrics to estimate reliability of control room operators. Journal of Loss Prevention in the Process Industries, 56, 524–530. doi: https://doi.org/10.1016/j.jlp.2017.10.011
15. Surya Atman, M. W., Noda, K., Funada, R., Yamauchi, J., Hatanaka, T., Fujita, M. (2019). On Passivity-Shortage of Human Operators for A Class of Semi-autonomous Robotic Swarms. IFAC-PapersOnLine, 51 (34), 21–27. doi: https://doi.org/10.1016/j.ifacol.2019.01.008
16. Khudyakova, E. P., Sedelkova, V. A., Tarasenkov, G. G., Chertopolokhov, V. A., Belousova, M. D., Natura, E. S. (2021). Characteristics of operator performance in controlling a virtual lunar rover during simulated lunar gravity. AIP Conference Proceedings. doi: https://doi.org/10.1063/5.0035989

17. Van Grootheest, H. A. (2017). Human-Operator Identification with Time-Varying ARX Models. TU Delft. Available at: https://repository.tudelft.nl/islandora/object/uuid:da69d1cf-3274-466f-bbc2-573f571d154e?collection=education
18. Abramov, Yu. O., Tyshchenko, Ye. O., Sobyna, V. O. (2017). Pat. No. 119180 UA. Mobilna pozhezhna ustanovka. No. u201704071; declareted: 24.04.2017; published: 11.09.2017, Bul. No. 17. Available at: https://uapatents.com/4-119180-mobilna-pozhezhna-ustanovka.html
19. Abramov, Yu., Basmanov, A. (2017). Modeli i kharakteristiki protsessa tusheniya pozharov klassa B. LAP LAMBERT Academic Publishing, 192.
20. Abramov, Yu. O., Sobyna, V. O., Khyzhniak, A. A., Zakora, O. V., Bezuhla, Yu. S. (2020). Pat. No. 143723 UA. Sposib vyznachennia dynamichnykh kharakterystyk operatora mobilnoi pozhezhnoi ustanovky. No. u202001028; declareted: 17.02.2020; published: 10.08.2020, Bul. No. 15. Available at: https://base.uipv.org/searchINV/search.php?action=viewdetails&IdClaim=270522
21. Abramov, Yu. O., Sobyna, V. O., Tyshchenko, Ye. O., Khyzhniak, A. A., Danilin, O. M. (2019). Pat. No. 135301 UA. Prystriy dlia vyznachennia kharakterystyk operatora mobilnoho pozhezhnoho robota. No. 201900596; declareted: 21.01.2019; published: 25.06.2019, Bul. No. 12. Available at: https://base.uipv.org/searchINV/search.php?action=viewdetails&IdClaim=259667