THE METHOD OF ACCOUNTING FOR SCATTERING ERRORS BY THE METHOD OF FUZZY SETS IN STRENGTH MODELS OF RADIO ELEMENTS MOUNTED ON PRINTED CIRCUIT BOARDS OF ELECTRONIC DEVICES

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Abstract: The problem of taking into account uncertainty factors in the form of variations of the initial physical, mechanical and geometric parameters in the mathematical modeling of resonant elastic vibrations of radio elements attached to circuit boards at the terminals is considered. The aim of the study is to obtain updated data on the values of the output parameters of the output operation time in the mode of occurrence of resonant oscillations and the number of cycles of resonant oscillations before destruction. To solve the problem under consideration, an approach is proposed based on the introduction of fuzzy-interval descriptions for its non-contrasting initial parameters. As a result of the implementation of the developed method in the form of decompositions over α-level sets, representations are obtained for calculating fuzzy-multiple endogenous parameters of the model in relation to various forms of resonant vibrations of radio elements in the case of rigid pinning of the pins on the board.

Key words: circuit boards of electronic devices, strength models of radio elements, radio elements fixed on the leads, resonance elastic vibrations, fuzzy-set technique, heuristic principle of generalization.

1. INTRODUCTION

When modeling mechanical effects on devices and components of electronic equipment [1-4], methods of accounting for the uncertainty of the values of the initial parameters of the structures, components and work processes under consideration are in high demand. However, the use of verified methods of probabilistic-stochastic analysis for this purpose is complicated in some cases by the fact that the initial information about the variations of exogenous parameters of models to be taken into account often does not meet the criteria of its statistical nature or is based on subjective expert opinions, and the type of frequency distribution should be specified a priori for the resulting parameters. At the same time, as an additional approach to the study of uncertainty factors in models of this type, the application of methods of the theory of fuzzy sets [5-10], which impose milder requirements on the nature of the initial non-contrast information, can be considered.

The purpose of this work is to develop a fuzzy-multiple approach to models with non-contrasting initial parameters for estimating the dynamic strength of radio elements attached to circuit boards on terminals. The proposed method is based on the use of deterministic versions of applied calculation relations for the model under consideration, in which, using a modified α-level form of the heuristic principle of expansion and step-by-step fragmented application of the apparatus of arithmetic of fuzzy quantities, a transition to non-contrasting fuzzy-multiple arguments is carried out.

2. BASIC RELATIONS OF DETERMINISTIC VERSIONS OF THE STRENGTH MODELS OF RADIO ELEMENTS FIXED ON THE LEADS

Fatigue failures of radio elements fixed to the terminals (Figure 1) in the form of microcircuits, diodes, capacitors, resistors caused by resonant mechanical vibrations of circuit boards are the leading cause of the dominant number of failures of electronic devices. The applied scheme of their strength calculations is based on the interpretation of the elements fixed on the terminals as U-shaped frames of beams exposed to inertial forces [4].

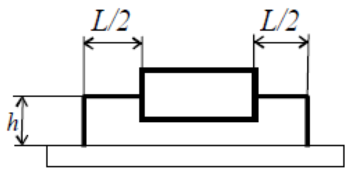

Fig 1. The scheme of fixing the radio element to the terminals

As applied calculation relations of the deterministic version of the model under consideration for the lower resonant frequencies f_i of various forms of vibrations of U-shaped frames with vertical fragments of length h and horizontal fragment of length L, interpreting radio elements fixed to the terminals when they are modeled by point masses m and under conditions of rigid contact of vertical fragments with the base of the board, expressions of the form [9]:

$$f_1(E,m,L,h,d) = (2\pi)^{-1}(24Bg\ (mh^3(1+3(6k+1)^{-1}))^{-1})^{1/2} \quad (1)$$

$$f_2(E,G,m,L,h,d) = (2\pi)^{-1}(2gB\ m^{-1}(L^3/24 + h^3/3 - GJL^4(32(2hB+GJL))^{-1})^{-1})^{1/2} \quad (2)$$

$$f_3(E,m,L,h,d) = (2\pi)^{-1}(48Bg\ (mL^3(1-3(2k+4)^{-1}))^{-1})^{1/2} \quad (3)$$

where $B=EJ$; $k=h/L$; J – the bending moment of inertia of the output section; E, G – respectively the Young's modulus and the shear modulus for the output material; g – the parameter of acceleration of free fall. For circular cross-section leads with a diameter of d:

$$J = \pi d^4/64 \quad (4)$$

Representation (1) describes the lowest resonant frequency of vibrations with a shape F_1 lying in the plane of the frame and characterized by non-zero horizontal displacements of the point mass m. The representation (2) corresponds to the shape of vibrations coming out of the plane of the frame F_2, and the formula (3) describes the resonant frequency of vibrations with a symmetrical shape lying in the plane of the frame F_3, characterized only by vertical displacements of the point mass m. When oscillating with these shapes F_j, the values of bending moments $M_1^{(j)}$ at the points of contact of the terminals and the board (the bases of the sides of the frame) and moments $M_2^{(j)}$ at the points of inflection of the terminals (the contact of the vertical and horizontal sides of the frame) are described by the relations [9]

$$M_1^{(1)} = P_1h/2,\ M_2^{(1)} = 3P_1kh/(12k+2),\ M_1^{(2)} = P_2h/2,$$
$$M_2^{(2)} = P_2L^3/(8Eh/3+8L),\ M_1^{(3)} = P_3L/(8k+16), \quad (5)$$
$$M_2^{(3)} = P_3L/(4k+8)$$

where $P_j\ \ (j=\overline{1,3})$, respectively, the projections of inertia forces when the point mass is displaced along the upper side of the frame, in the horizontal direction perpendicular to the upper side of the frame and in the vertical direction. Based on the results of calculations $f_j, P_j\ \ (j=\overline{1,3})$, estimates are formed for the operating time t_c of the output before destruction in the mode of occurrence of resonant oscillations

$$t_c = N_c/f \quad (6)$$

Here the parameter of the number N_c of cycles of resonant oscillations before destruction has the expression

$$N_c = (\sigma_r/\sigma_{\max})^n N_\delta \quad (7)$$

where σ_r is the fatigue failure limit for the output material, $\sigma_{\max}$ is the maximum stress in the output sections, N_δ is the parameter of the base number of cycles, n is an empirical parameter with a value determined, in particular, by the size, shape and material of the output. To output a circular section

$$\sigma_{\max} = (2J)^{-1} M_{\max} d = (32/\pi) M d^{-3} \quad (8)$$

where $M_{\max}$ is determined from expressions (5) for the corresponding value of the natural frequency and the shape of the resonant oscillation. Accordingly, the values $P_j \ (j = \overline{1,3})$ in the calculations of $M_{\max}$ are described by expressions

$$P = \mu m \xi\,,\ \mu = \pi\lambda^{-1}\,,\ \lambda = \pi f^{-1/2} \quad (9)$$

in which μ – the transmission coefficient at resonance, λ – the logarithmic decrement of oscillations, ξ – the parameter of acceleration of vibration excitation

3. FUZZY-SET ACCOUNTING OF SCATTER ERRORS FOR STRENGTH MODEL PARAMETERS

It is assumed that information on the spread of experimental reference data and technological tolerances for the values E, G, d, h, L, σ_r, N_δ, n allows, based on fuzzification, to proceed to representations of the exogenous parameters of the model under consideration in the form of normal trapezoidal fuzzy intervals $\tilde{E}$, $\tilde{G}$, $\tilde{d}$, $\tilde{h}$, $\tilde{L}$, $\tilde{\sigma}_r$, $\tilde{N}_\delta$, $\tilde{n}$ with corresponding tuples of reference values and decompositions over sets of α-slices [5-7]:

$$\tilde{E} = (E_1, E_2, E_3, E_4) = \bigcup_{\alpha\in[0,1]} [\underline{E}_\alpha, \overline{E}_\alpha],\ \tilde{G} = (G_1, G_2, G_3, G_4) = \bigcup_{\alpha\in[0,1]} [\underline{G}_\alpha, \overline{G}_\alpha],$$
$$\tilde{d} = (d_1, d_2, d_3, d_4) = \bigcup_{\alpha\in[0,1]} [\underline{d}_\alpha, \overline{d}_\alpha],\ \ldots,\ \tilde{n} = (n_1, n_2, n_3, n_4) = \bigcup_{\alpha\in[0,1]} [\underline{n}_\alpha, \overline{n}_\alpha],$$
$$\underline{E}_\alpha = (1-\alpha)E_1 + \alpha E_2,\ \overline{E}_\alpha = \alpha E_3 + (1-\alpha)E_4;\ \underline{G}_\alpha = (1-\alpha)G_1 + \alpha G_2, \quad (10)$$
$$\overline{G}_\alpha = \alpha G_3 + (1-\alpha)G_4;\ \underline{d}_\alpha = (1-\alpha)d_1 + \alpha d_2,\ \overline{d}_\alpha = \alpha d_3 + (1-\alpha)d_4;\ \ldots;$$
$$\underline{n}_\alpha = (1-\alpha)n_1 + \alpha n_2,\ \overline{n}_\alpha = \alpha n_3 + (1-\alpha)n_4.$$

Special cases of (10) are representations $\tilde{E}$, $\tilde{G}$, $\tilde{d}$, $\tilde{h}$, $\tilde{L}$, $\tilde{\sigma}_r$, $\tilde{N}_\delta$, $\tilde{n}$ in the form of normal triangular fuzzy numbers for which

$$\tilde{E} = (E_1, E_2, E_3) = \bigcup_{\alpha\in[0,1]} [\underline{E}_\alpha, \overline{E}_\alpha],\ \underline{E}_\alpha = (1-\alpha)E_1 + \alpha E_2,$$
$$\overline{E}_\alpha = \alpha E_2 + (1-\alpha)E_3;\ \ldots; \quad (11)$$
$$\tilde{n} = (n_1, n_2, n_3) = \bigcup_{\alpha\in[0,1]} [\underline{n}_\alpha, \overline{n}_\alpha],\ \underline{n}_\alpha = (1-\alpha)n_1 + \alpha n_2,\ \overline{n}_\alpha = \alpha n_2 + (1-\alpha)n_3$$

When implementing the full cycle of the study of the model under consideration with non-contrasting fuzzy–multiple parameters, at the first step, the heuristic principle of expansion in a modified α-level [7-10] form is applied to the relations (1)-(3). Taking into account the properties performed in the areas of definition of the corresponding function

$$\partial f_1(E,m,L,h,d)/\partial \mathrm{E} > 0,\ \partial f_1(E,m,L,h,d)/\partial \mathrm{m} < 0,\ \partial f_1(E,m,L,h,d)/\partial \mathrm{d} > 0;$$
$$\partial f_2(E,G,m,L,h,d)/\partial m < 0;\ \partial f_3(E,m,L,h,d)/\partial \mathrm{E} > 0, \qquad (12)$$
$$\partial f_3(E,m,L,h,d)/\partial \mathrm{m} < 0,\ \partial f_3(E,m,L,h,d)/\partial \mathrm{d} > 0;$$

fuzzy-multiple representations are formed:

$$\tilde f_1(\tilde E,\tilde m,\tilde L,\tilde h,\tilde d) = \bigcup_{\alpha\in[0,1]} [\underline{f}_{1\alpha}, \overline{f}_{1\alpha}],\ \tilde f_2(\tilde E,\tilde G,\tilde m,\tilde L,\tilde h,\tilde d) = \bigcup_{\alpha\in[0,1]} [\underline{f}_{2\alpha}, \overline{f}_{2\alpha}],$$
$$\tilde f_3(\tilde E,\tilde m,\tilde L,\tilde h,\tilde d) = \bigcup_{\alpha\in[0,1]} [\underline{f}_{3\alpha}, \overline{f}_{3\alpha}] \qquad (13)$$

where

$$\underline{f}_{1\alpha} = \inf_{\substack{L\in[\underline{L}_\alpha,\overline{L}_\alpha]\\ h\in[\underline{h}_\alpha,\overline{h}_\alpha]}} f_1(\underline{E}_\alpha,\overline{m}_\alpha,L,h,\underline{d}_\alpha),\ \overline{f}_{1\alpha} = \sup_{\substack{L\in[\underline{L}_\alpha,\overline{L}_\alpha]\\ h\in[\underline{h}_\alpha,\overline{h}_\alpha]}} f_1(\overline{E}_\alpha,\underline{m}_\alpha,L,h,\overline{d}_\alpha); \qquad (14)$$

$$\underline{f}_{2\alpha} = \inf_{\substack{E\in[\underline{E}_\alpha,\overline{E}_\alpha]\\ G\in[\underline{G}_\alpha,\overline{G}_\alpha]\\ L\in[\underline{L}_\alpha,\overline{L}_\alpha]\\ h\in[\underline{h}_\alpha,\overline{h}_\alpha]\\ d\in[\underline{d}_\alpha,\overline{d}_\alpha]}} f_2(\mathrm{E},G,\overline{m}_\alpha,L,h,d),\ \overline{f}_{2\alpha} = \sup_{\substack{E\in[\underline{E}_\alpha,\overline{E}_\alpha]\\ G\in[\underline{G}_\alpha,\overline{G}_\alpha]\\ L\in[\underline{L}_\alpha,\overline{L}_\alpha]\\ h\in[\underline{h}_\alpha,\overline{h}_\alpha]\\ d\in[\underline{d}_\alpha,\overline{d}_\alpha]}} f_2(\mathrm{E},G,\underline{m}_\alpha,L,h,d); \qquad (15)$$

$$\underline{f}_{3\alpha} = \inf_{\substack{L\in[\underline{L}_\alpha,\overline{L}_\alpha]\\ h\in[\underline{h}_\alpha,\overline{h}_\alpha]}} f_3(\underline{E}_\alpha,\overline{m}_\alpha,L,h,\underline{d}_\alpha),\ \overline{f}_{3\alpha} = \sup_{\substack{L\in[\underline{L}_\alpha,\overline{L}_\alpha]\\ h\in[\underline{h}_\alpha,\overline{h}_\alpha]}} f_3(\overline{E}_\alpha,\underline{m}_\alpha,L,h,\overline{d}_\alpha). \qquad (16)$$

Further, using fuzzy-multiple exogenous parameters $\tilde\sigma_r$, $\tilde N_\delta$, $\tilde n$, $\tilde\xi$ in the form of normal fuzzy trapezoidal intervals or normal triangular fuzzy numbers introduced by representations (10), (11) based on fuzzification of non–contrast initial data, for the fixed form of resonant vibrations, based on the ratios (5)-(9), fuzzy-multiple characteristics are consistently determined $\tilde\lambda$, $\tilde\mu$, $\tilde P$, $\tilde M_{\max}$, $\tilde\sigma_{\max}$, $\tilde N_c$, $\tilde t_c$:

$$\tilde\lambda = \bigcup_{\alpha\in[0,1]}[\underline{\lambda}_\alpha, \overline{\lambda}_\alpha],\ \underline{\lambda}_\alpha = \pi(\overline{f}_\alpha)^{-1/2},\ \overline{\lambda}_\alpha = \pi(\underline{f}_\alpha)^{-1/2}; \qquad (17)$$

$$\tilde\mu = \bigcup_{\alpha\in[0,1]}[\underline{\mu}_\alpha, \overline{\mu}_\alpha],\ \underline{\mu}_\alpha = \pi(\overline{\lambda}_\alpha)^{-1},\ \overline{\mu}_\alpha = \pi(\underline{\lambda}_\alpha)^{-1}; \qquad (18)$$

$$\tilde P = \bigcup_{\alpha\in[0,1]}[\underline{P}_\alpha, \overline{P}_\alpha],\ \underline{P}_\alpha = \underline{\mu}_\alpha \underline{m}_\alpha \underline{\xi}_\alpha,\ \overline{P}_\alpha = \overline{\mu}_\alpha \overline{m}_\alpha \overline{\xi}_\alpha; \qquad (19)$$

$$\tilde M_1^{(1)} = \bigcup_{\alpha\in[0,1]}[\underline{M}_{1\alpha}^{(1)}, \overline{M}_{1\alpha}^{(1)}],\ \underline{M}_{1\alpha}^{(1)} = \underline{P}_{1\alpha}\underline{h}_\alpha/2,\ \overline{M}_{1\alpha}^{(1)} = \overline{P}_{1\alpha}\overline{h}_\alpha/2; \qquad (20)$$

$$\tilde{M}_2^{(1)} = \bigcup_{\alpha\in[0,1]} [\underline{M}_{2\alpha}^{(1)}, \overline{M}_{2\alpha}^{(1)}],$$

$$\underline{M}_{2\alpha}^{(1)} = \inf_{\substack{L\in[\underline{L}_\alpha, \overline{L}_\alpha] \\ h\in[\underline{h}_\alpha, \overline{h}_\alpha]}} 3\underline{P}_{1\alpha} h^2 L^{-1}(12h/L+2)^{-1}, \ \overline{M}_{2\alpha}^{(1)} = \sup_{\substack{L\in[\underline{L}_\alpha, \overline{L}_\alpha] \\ h\in[\underline{h}_\alpha, \overline{h}_\alpha]}} 3\overline{P}_{1\alpha} h^2 L^{-1}(12h/L+2)^{-1}; \quad (21)$$

$$\tilde{M}_1^{(2)} = \bigcup_{\alpha\in[0,1]} [\underline{M}_{1\alpha}^{(2)}, \overline{M}_{1\alpha}^{(2)}], \underline{M}_{1\alpha}^{(2)} = \underline{P}_{2\alpha}\underline{h}_\alpha/2, \overline{M}_{1\alpha}^{(2)} = \overline{P}_{2\alpha}\overline{h}_\alpha/2; \quad (22)$$

$$\tilde{M}_2^{(2)} = \bigcup_{\alpha\in[0,1]} [\underline{M}_{2\alpha}^{(2)}, \overline{M}_{2\alpha}^{(2)}],$$

$$\underline{M}_{2\alpha}^{(2)} = \inf_{L\in[\underline{L}_\alpha, \overline{L}_\alpha]} \underline{P}_{2\alpha} L^3 (8\overline{E}_\alpha \overline{h}_\alpha/3+8L)^{-1}, \ \overline{M}_{2\alpha}^{(2)} = \sup_{L\in[\underline{L}_\alpha, \overline{L}_\alpha]} \overline{P}_{2\alpha} L^3 (8\underline{E}_\alpha \underline{h}_\alpha/3+8L)^{-1}; \quad (23)$$

$$\tilde{M}_1^{(3)} = \bigcup_{\alpha\in[0,1]} [\underline{M}_{1\alpha}^{(3)}, \overline{M}_{1\alpha}^{(3)}],$$

$$\underline{M}_{1\alpha}^{(3)} = \inf_{L\in[\underline{L}_\alpha, \overline{L}_\alpha]} \underline{P}_{3\alpha} L(8\overline{h}_\alpha/L+16)^{-1}, \ \overline{M}_{1\alpha}^{(3)} = \sup_{L\in[\underline{L}_\alpha, \overline{L}_\alpha]} \overline{P}_{3\alpha} L(8\underline{h}_\alpha/L+16)^{-1}; \quad (24)$$

$$\tilde{M}_2^{(3)} = \bigcup_{\alpha\in[0,1]} [\underline{M}_{2\alpha}^{(3)}, \overline{M}_{2\alpha}^{(3)}], \quad (25)$$

$$\underline{M}_{2\alpha}^{(3)} = \inf_{L\in[\underline{L}_\alpha, \overline{L}_\alpha]} \underline{P}_{3\alpha} L(4\overline{h}_\alpha/L+8)^{-1}, \ \overline{M}_{2\alpha}^{(3)} = \sup_{L\in[\underline{L}_\alpha, \overline{L}_\alpha]} \overline{P}_{3\alpha} L(4\underline{h}_\alpha/L+8)^{-1}; \quad (26)$$

$$\tilde{\sigma}_{max} = \bigcup_{\alpha\in[0,1]} [\underline{\sigma}_{max,\alpha}, \overline{\sigma}_{max,\alpha}],$$

$$\underline{\sigma}_{max,\alpha} = (32/\pi)\underline{M}_{max,\alpha}(\overline{d}_\alpha)^{-3}, \quad \overline{\sigma}_{max,\alpha} = (32/\pi)(\underline{d}_\alpha)^{-3} \quad (27)$$

$$\tilde{N}_c = \bigcup_{\alpha\in[0,1]} [\underline{N}_{c\alpha}, \overline{N}_{c\alpha}],$$

$$\underline{N}_{c\alpha} = \inf_{\substack{\sigma_r\in[\underline{\sigma}_{r\alpha}, \overline{\sigma}_{r\alpha}] \\ \sigma_{max}\in[\underline{\sigma}_{max,\alpha}, \overline{\sigma}_{max,\alpha}] \\ n\in[\underline{n}_\alpha, \overline{n}_\alpha]}} (\sigma_r/\sigma_{max})^n \underline{N}_{\delta\alpha}, \ \overline{N}_{c\alpha} = \sup_{\substack{\sigma_r\in[\underline{\sigma}_{r\alpha}, \overline{\sigma}_{r\alpha}] \\ \sigma_{max}\in[\underline{\sigma}_{max,\alpha}, \overline{\sigma}_{max,\alpha}] \\ n\in[\underline{n}_\alpha, \overline{n}_\alpha]}} (\sigma_r/\sigma_{max})^n \overline{N}_{\delta\alpha}; \quad (28)$$

$$\tilde{t}_c = \bigcup_{\alpha\in[0,1]} [\underline{t}_{c\alpha}, \overline{t}_{c\alpha}], \ \underline{t}_{c\alpha} = \underline{N}_{c\alpha}/\overline{f}_\alpha, \ \overline{t}_{c\alpha} = \overline{N}_{c\alpha}/\underline{f}_\alpha \quad (29)$$

In addition to the calculated ratios (17)–(29) for fuzzy-multiple endogenous characteristics, defuzzification indicators are to be determined by the method of centers of gravity and the method of medians, as characteristics of averaging the results of fuzzy-multiple analysis.

4. CONCLUSION

The result of the research presented in this paper is the development of a theoretical numerical-analytical algorithm for analyzing the effect of variations in the values of the initial structural parameters of the design schemes of strength and reliability resource for the components of the element base on the boards of electronic devices when their resonant oscillations occur.

An approach based on the theory of fuzzy calculations and involving a transition to non-contrast arguments with fuzzy-multiple descriptions in the calculated ratios of deterministic versions of the models under consideration based on the application of a modified level form of the heuristic generalization principle is applied.

Applied fuzzy-multiple calculation relations for non-contrasting endogenous parameters of the output operation time in the mode of occurrence of resonant oscillations and the number of cycles of resonant oscillations before destruction are obtained.

REFERENCES

[1] Besimi N., Çiço B., Shehu V., Besimi A. Evaluation of Machine Learning Techniques for Research Articles Recommendation. *International Journal on Information Technologies and Security*, No. 1 (vol. 12), 2020, pp. 75-86.

[2] Al-Fadhli F.H.K., Al-Araji Z.H., Swaikat N., Muratov A.V., Turetsky A.V. The perfect position of electrical components on PCBs in communication system industry. From the mechanical aspects' viewpoint. *Journal of Mechanical Engineering Research and Developments*, No. 4 (vol. 43), 2020, pp. 82-91.

[3] Oleinikova S.A., Kravets O.Ja., Aksenov I.A., Frantsisko O.Yu., Rahman P.A., Atlasov I.V. The General Scheme of the Genetic Algorithm for Solving the Task Scheduling Problem for a Multistage System and Assigning Time for Jobs. *International Journal on Information Technologies and Security*, No. 4 (vol. 13), 2021, pp. 47-58.

[4] Kovtun I.I., Boiko J.M., Petrashchuk S.A. Mathematical model for dynamic force analysis of printed circuit boards. *Journal of Physics: Conference Series,* No. 2021 (vol. 1921), 2021, Article No 012120. doi:10.1088/1742-6596/1921/1/012120.

[5] Chandrasekaran S., Tamilmani E. Applications of Fuzzy Number Mathematics. *International Journal of Innovative Science, Engineering & Technology,* No. 11 (vol. 2), 2015, pp. 149–176.

[6] Gritsyuk V. Application of the Fuzzy Robust Regression Analysis, a Case of Fuzzy Dependent Variable. *International Journal on Information Technologies and Security*, No. 3 (vol. 12), 2020, pp. 25-36.

[7] Ngueyn Quoc Shi, Chan Ba Le Hoang, Storozhev S.V. *The study of high-temperature thermal stabilization models with fuzzy parameters.* Yelm, WA, USA: Science Book Publishing House, 2019, 216 p.

[8] Storozhev S.V., Storozhev V.I., Vyskub V.G., Duong Minh Hai, Bolnokin V.E. Fuzzy-multiple estimates of the parameter uncertainty influence in the computing devices elements calculating theory. *Journal of Physics: Conference Series,* No. 2019 (vol. 1399), 2019, Article No 044028. doi:10.1088/1742-6596/1399/4/044028.

[9] Bolnokin V.E., Mutin D.I., Mutina E.I., Storozhev S.V., Storozhev V.I. Accounting of data uncertainty in advanced technological models of design calculations of acoustoelectronic components from piezoelectric materials. *IOP Conf. Series: Materials Science and Engineering*, No 2020 (vol. 862), 2020, Article No 022006. doi:10.1088/1757-899X/862/2/022006.

[10] Bolnokin V.E., Storozhev V.I., Duong Minh Hai, Mutin D.I. The models of thermoelastic deformation of thin elliptic boundary contours plates with accounting uncertainty factors. *International Journal on Information Technologies & Security,* No. 4 (vol. 12), 2020, pp. 77–82.

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