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A Few Remarks About the Most Important Element of Metrology — Person

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***Abstract.* The article considers a person as an element of metrology. His functional duties and specific actions are not taken into account. The metrologist is presented as a two-phase system, including two stages of the life cycle, the first cycle of which is a phase of concentration - work for effect, the second cycle - a phase of chaos, consisting in the restoration of spent energy to continue the first phase. A formal model of a person-metrologist is presented. The duration of the inter-verification period, optimal in terms of the availability factor, and the average number of object repairs per one year have been determined. With the help of the real model the average age of the person operator in terms of maximum availability, with and without preventive periods has been determined. In the formal and real person-operator models, the distribution of person lifespan is determined by the statistically extreme Weibull distribution law. From the formal point of view the chaos environment is characterized by a probability distribution function opposite to the concentration environment distribution function according to P. Levy.**

***Keywords:* metrologist, metrology, two-phase system, concentration environment, chaos environment, average failure rate, concentration function, concentration assurance.**

Introduction

Metrology traces its history back to ancient times, but only in the XX century did it become one of the main fundamental sciences. Metrology is divided into three main sections. Theoretical, or fundamental — considers general theoretical problems (development of the theory and problems of measuring physical quantities, their units, measurement methods). Applied — studies the issues of practical application of theoretical metrology developments. She is in charge of all issues of metrological support. Legislative — establishes mandatory technical and legal requirements for the use of units of physical quantities, methods and measuring instruments.

It is appropriate to raise the question of the main element of the science of metrology - the metrologist. In foreign and domestic literature, many works are devoted to the person operator [1–10]. Basically, they deal with aspects of the interaction of a person and a team with hardware and software systems. However, in our opinion, studying the elements of metrology (such as standards, measuring instruments) and their practical significance, we have the right to consider the most modern metrologist from a technical point of view as a metrological element, and in a broader sense - as a living metrological system. The aim of the article is to study the person metrologist as a metrological element.

Formal model of a person metrologist

First, let us consider a prototype of a model — a technical model — using the example of «average failure rate and availability factor of a measuring device, taking into account its metrological checks» [11]. To assess the reliability of restored objects, the reliability indicator is used — the average failure rate [12].

In this article, the average failure rate of recoverable objects is considered under the condition that periodic preventive maintenance is carried out at the facilities. It is assumed that during restoration and prevention, the object is restored completely to its original state.

The article posed the task of determining the average failure rate of an object on which state checks can be periodically carried out. With them, the object could be in a functional state, but requiring updating, for example, by adjusting its parameters. When a failure was detected, the object was replaced with a new one. An integral equation was derived for the corresponding average failure rate of the object, and its properties were investigated. The purpose of the article was to establish the first connection between the reliability indicators of hardware and software objects with metrological indicators that make up a necessary part of ensuring the quality of objects.

The following designations were adopted: $\omega(t)$ — average failure rate; $a(t)$ — probability density of time to failure; $Q(t)$, $P(t)$ — likelihood of failure and the likelihood of failure-free operation; $U(t)$ — function of time distribution of the beginning of verification; $v(t)$ — density of the probability of the duration of the verification and adjustment of the parameters of the object; $g(t)$ — distribution density of the recovery time of an object after a failure; τ — moment of the appointment of the first verification; θ — moment before the first failure occurs.

The average failure rate was determined by the sum of three components corresponding to the following inconsistent events:

- there was exactly one refusal of the object in time t, provided that verification was not scheduled during this time;

- there were several object failures within t time, provided that the first failure occurred before the appointment of the first verification;

- there were several object failures within t time, provided that the first verification was scheduled before the first failure occurred.

Then the expression for the average failure rate took the form:

$$\omega(t) = a(t) \times [1 - U(t)] + \\ + \int_0^t [1 - U(t)] \times a(\tau) \times \omega(t-\tau)d\tau + \\ + \int_0^t [1 - Q(\tau)] \times \int_0^{t-\tau} v(\theta) \times \omega(t-\tau-\theta)d\theta dU(\tau). \quad (1)$$

Expression (1) is obtained under the condition that after refusal and verification, the object is replaced by a serviceable (new) one instantly. The control over the state of the object's elements is perfect. For (1), the Laplace transform of the mean frequency is determined:

$$\omega^*(s) = \frac{a^*(s)}{1 - a^*(s) - b^*(s)v^*(s)}, \quad (2)$$

where

$$a^*(s) = \int_0^\infty a(z)[1 - U(z)]e^{-sz}\,dz;$$

$$b^*(s) = \int_0^\infty [1 - Q(z)]e^{-sz}dU(z). \quad (3)$$

The image of the probability density of the duration of the verification and adjustment of the object parameters was represented by the sum of two random components, therefore the Laplace image is equal to:

$$v^*(s) = u^*(s) \times r^*(s), \quad (4)$$

where $u^*(s)$, $r^*(s)$ — are the images of the time densities of verification and adjustment. In practice, checks on objects are carried out regularly, so it makes sense to consider a degenerate distribution as $U(t)$, i. e.

$$U(t) = \begin{cases} 0, t \lhd T \\ 1, t \geq T \end{cases}, \quad (5)$$

where T — the period between adjacent verifications.

From expression (2), taking into account formulas (3)–(5), under the condition of long-term operation of the object, a steady-state value of the average failure rate was obtained:

$$\omega(\infty, T) = \frac{Q(T)}{\int_0^T P(z)dz + t_{ur}P(T)}, \quad (6)$$

where t_{ur} — average duration of one verification with parameter adjustment.

Reasoning in a similar way, we got $\omega(t)$, $\omega^*(s)$, $\omega(\infty, T)$ for a situation when the restoration of an object was not performed instantly, but after a random time:

$$\omega(t) = a(t)[1 - U(t)] + \\ + \int_0^t [1 - U(\tau)] \int_0^{t-\tau} g(\theta)\omega(t-\tau-\theta)d\theta a(\tau)d\tau + \quad (7) \\ + \int_0^t [1 - Q(\tau)] \int_0^{t-\tau} v(\theta)\omega(t-\tau-\theta)d\theta dU(\tau);$$

$$\omega^*(s) = \frac{a^*(s)}{1 - a^*(s)g^*(s) - b^*(s)v^*(s)};$$

$$\omega(\infty, T) = \frac{Q(T)}{\int_0^T P(z)dz + t_r Q(T) + t_{ur}P(T)},$$

where t_r — is the average recovery time of the object.

From expressions (6) and (7), provided that verification is not performed ($T \to \infty$), there follow the known special cases of stationary values of the average frequency:

$$\omega(\infty, \infty) = \frac{1}{T_{av}},$$

$$\omega(\infty, \infty) = \frac{1}{t_{av} + t_r},$$

where t_{av} — is the average time of no-failure operation of the object.

USE CASE $\omega(\infty, T)$

It is required to determine the optimal in terms of availability factor the duration of the calibration period T_0 and the average number of repairs n_p of the object per one year, if the distribution law of the object's operation time to failure is Weibull's law with the parameter values:

$$\lambda_0 = 1 \times 10^{-5}\ \text{h}^{-k},\ k = 2.5.$$

The average time to repair an object after a failure is $t_r = 10$ h, and the average duration of verification and adjustment of the object's parameters is $t_{ur} = 2$ h. It is easy to verify that the stationary value of the facility availability factor is:

$$K_G = K_G(\infty, T) = \frac{\int_0^T P(z)dz}{\int_0^T P(z)dz + t_v Q(T) + t_{ur}P(T)}, \quad (8)$$

where $P(t) = e^{-\lambda_0 t^k}$, $Q(t) = 1 - P(t)$.

The quantity T_0, leading to the maximum (7) satisfies the equation:

$$\frac{t_r}{t_r - t_{ur}} = \lambda(T_0) \int_0^{T_0} P(z)dz + P(T_0), \quad (9)$$

in which $\lambda(t)$ — is the failure rate of the object.

It should be noted that expressions (8) and (9) coincide with expressions obtained in [13] in a different way.

The results of calculations according to formulas (7) and (8) are shown in Figure 1. The maximum value of $K_G = 0{,}95$ is achieved at $T_0 \approx 50$ h. The average failure rate of $T_0 \approx 50$ h corresponds to the average frequency of failures $\omega(\infty, T_0) \approx 0.00351$ per hour. The average time of no-failure operation of the facility without verification is $T_{av} \approx 89$ h, and with their verification is $T_{av} \approx 285$ h. The average expected number of repairs of the facility during the year without carrying out checks $n_p \approx 100$, and with their carrying out $n_p \approx 31$. The total operating time of the facility during the year increases by an average of half a month.

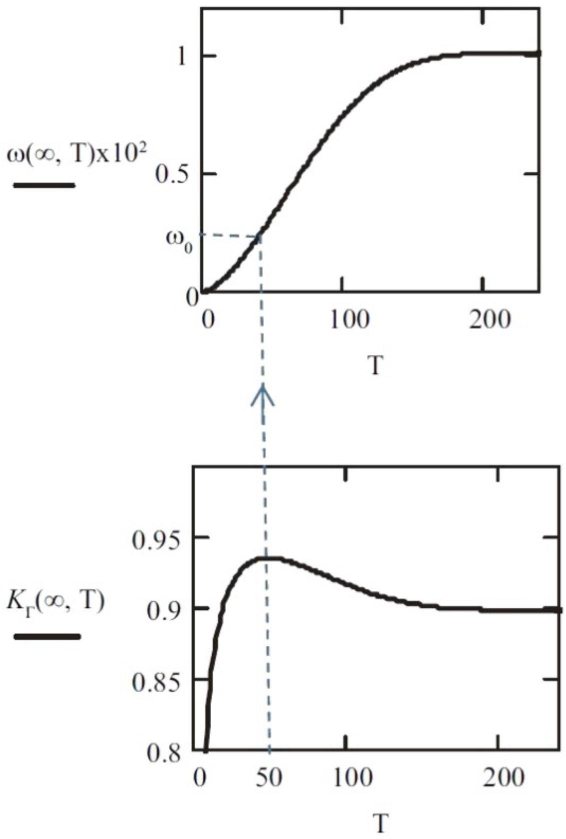

Fig. 1. Dependences of the average failure rate ω and the availability factor of the object K_G on the duration of the period *T* between checks

Let us consider a rather small inverse problem of metrology: how, for a given availability factor, to determine the requirement for the value of the average duration of verification and regulation of an object? For this, from expression (8) we find the value t_{ur}. It will be represented by the expression:

$$t_{ur} = \frac{\int_0^T P(z)dz}{P(T)} \times \frac{1 - K_G}{K_G} - t_r \frac{Q(T)}{P(T)}. \qquad (10)$$

It is also possible to represent the solution of equation (8) with respect to t_{ur} in the form

$$t_{ur} = t_r \left(1 - \frac{1}{\lambda(T_0) \int_0^{T_0} P(z)dz + P(T_0)}\right).$$

Graphical representation (10) is shown in Figure 2. It follows that the inflection point coordinate $t_{ur}(50) = 2.055$ h corresponds to the optimal solution.

We have considered an example of a typical operation of a complex technical system. Let's make one remark that this example is not typical for a person — a measuring device.

The remark concerns the fact that the standard deviation (RMSD) is not typical for the life of a person who is in both normal and stressful situations. The calculation shows that with an average device lifetime of 89 hours, not years, the standard deviation is 38 028 hours. Replacing the unit «hour» with the unit «year» clarifies the remark made. Therefore, based on the Weibull distribution, we will select an example that is real for a person — a measuring device.

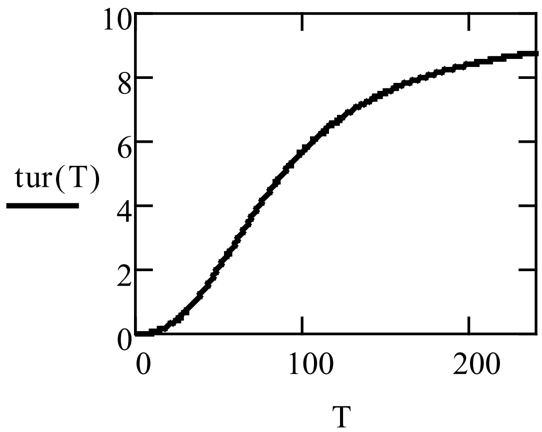

Fig. 2. Dependence of the duration of one verification with the adjustment of parameters on the duration of the period *T* between verifications

Real model of person metrologist

So, we define the distribution of the life time of a person metrologist by the Weibull distribution law $F(x) = e^{-\lambda_0 \times x^k}$, extreme in statistics. Let's select the values of the following parameters: $\lambda_0 = 1 \times 10^{-5}$ year, $k = 2.8$. Then the average age of the metrologist is $v_1 = 54.4$ year; the second initial moment is $v_2 = 3\,307.4$ years and the standard deviation of the age is $\sigma = 21.0$ year. This means that the period of his career is in the range from 33.4 to 75.4 years. We also take the value of the average duration of recovery of a person metrologist after an illness $t_r = 3$ months and the value of the average duration of his preventive maintenance during the period of work $t_p = 1$ month.

Applying the calculations of the previous article material, we get the following graphical results. Figure 3 shows a graph of the readiness function, and Figure 4 shows a graph of the average failure rate (disease) of a person metrologist. Figure 5 shows the probability of continuous work of a metrologist during his life.

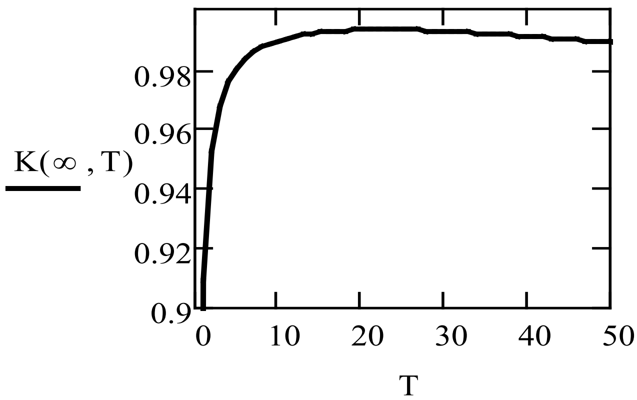

Fig. 3. Ready function

Years are indicated along the abscissas of all graphs. Based on the graph in Figure 3, it can be argued that the maximum availability factor $K_G(\infty, 25) = 0.993$ is achieved with the value of the optimal periodic preventive maintenance $T_0 = 25$ years. In this case, the average frequency of failures (diseases) is

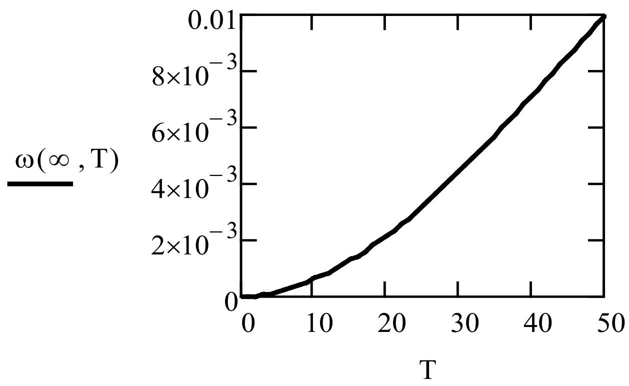

Fig. 4. Dependence of the average frequency of failures (diseases) of the metrologist on the duration of the period *T* between verifications

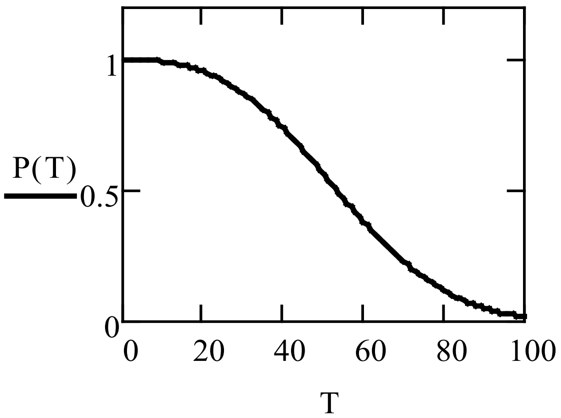

Fig. 5. Probability of continuous trouble-free operation of the metrologist depending on the lifetime

$\omega(\infty, 25) = 3{,}212 \times 10^{-3}$ year^{-1}. Figure 5 shows a graph of the probability of continuous trouble-free operation of a metrologist depending on the number of years. The results of calculations according to formulas (7) and (8) in relation to the initial data of the model of a person operator, presented in Figures 3 and 4, lead to the following additional quantitative data: if the average age of a person metrologist, excluding preventive maintenance, is $\nu_1 = 54.4$ year, of service it will be $^{1}/_{\omega(\infty,25)}$ year^{-1} $= 311.333$ year. The average number of required restorations in one year will be $1/54.277 = 0.018$ once. Taking into account preventive maintenance with an optimal frequency of $1/311.333 = 3.212 \times 10^{-3}$ within one year, it will be $0.018 \times 0.25 = 4.5 \times 10^{-3}$ years. Time costs per year for treatment will be on average

$$3.212 \times 10^{-3} \times {}^{1}/_{12} = 2.677 \times 10^{-4} \text{ years.}$$

Thus, the gain in time to restore health per year will be on average $(4.5 \times 10^{-3})/(2.677 \times 10^{-4}) = 16.81$ times due to the periodic preventive maintenance of a person metrologist. These conclusions apply only to those setting data of the example that we have given.

On the relationship between the distribution functions of concentration and chaos

Unlike technical and software systems and their elements — measuring devices, which can function when working as intended or be restored, the measuring system «person metrologist» can also be in the two named states, but these paired states are different. If the first systems are restored in their inherent technical environment, then the second, according to their states, can be attributed to systems of a seasonal type. After they leave the state of work in a technical environment, they find themselves in a different environment that differs from the first in another property. If the systems of the first type are associated with the phenomenon of concentration of the produced product, with the receipt of a significant effect, then the systems of the second type, on the contrary, are associated with liberation from the process of concentration of the product, but on the contrary, they are removed from this need for production, go into a state of rest, relaxation, organized indifference, roughly speaking — controlled chaos.

Here, chaos is understood as the acquisition of such properties, without which it is impossible to return to systems that have the properties of the first systems. Namely, if the systems periodically change the indicated properties of the two named systems, but on the whole pass from one type to another and vice versa, then we call such systems seasonal. The seasonality of systems is the basis of the life cycle, their dialectical unity. Thanks to it, the economic growth of the state, progress in civilization, science, the welfare of the nation, its defense capability and others are possible.

An abstract example

The subject, functioning in the concentration mode with parameter t_k and duration x_k, has developed N. M. Sedyakin's resource r_k [14]. Subject then entered chaos mode with parameter t_x to restore the consumed resource. How long should it be in chaos mode, x_x, in order to restore the spent resource in concentration mode?

Formally, the modes are represented, as follows from the material presented [15–16]:

$$Q_F(x_k) = \max_{t_k}\big(F(t_k) - F(t_k + x_k + 0)\big),$$

$$W_F(x_x) = \max_{t_x}\big(F(t_x) - F(t_x + x_x + 0)\big),$$

where Q_F is the concentration distribution function, W_F is the chaos distribution function, F is the concentration resource function.

Recall that resources are defined as:

$$\begin{cases} rQ_F(x_k) = -\ln(1 - Q_F(x_k)) \\ rW_F(x_x) = -\ln(1 - W_F(x_x)). \end{cases} \quad (11)$$

Sets $[t_k], [t_x]$ are formed separately to solve the subject's problem. These sets can be used to implement various options for restoring the value of the lost resource of the metrologist's working capacity.

Taking into account the economic costs, it is possible to consider the optimal strategies of the seasonal type. Try to solve a similar problem. The question is not only how to determine the value of the restored resource, but how to make up for the loss of a part of the concentration resource. Or will it resume itself after the metrologist's preventive maintenance? But even in this case, it is of interest how the concentration function will change. In the simplest case, using formulas (11), one can solve the following problem. Knowing the value of the spent resource in the concentration mode $rQ_F(x_k)$, , one should substitute it instead of $rW_F(x_x)$ in the chaos formula and solve the resulting equation regarding the determination of time $x_x$in the chaos mode. And then perform a reverse recalculation of this time, using the equalities of the resource values in these two modes and find a new time value x_k and the corresponding resource value in the concentration mode. Add this value of the resource with the value of the previously residual resource in the concentration mode. Draw conclusions about further changes in the regime.

Example. We use the third subsection of the article. We will express all numerical data in hours, passing from measurement in years to hours (1 year = $8{,}76 \times 10^3$ hours).

Suppose that the metrologist performed work in the environment of concentration described by the concentration function of P. Levy

$$Q_F(x_k) = \max_h\big(F(h + x_k + 0) - F(h)\big)\,,$$

during the time $x_k = 60$ h with the set parameter $h = 30$ h and moved into the environment of chaos, described by the chaos function

$$W_F(x_k) = \max_{h_1}\big(F(h_1) - F(h_1 + x_k + 0)\big)\,,$$

to restore his lost performance. Question: how long will it take to restore the lost operational resource and return to continue working in concentration mode? (In this case, he will add the value of the restored working capacity to the value of the residual, saved working capacity in the concentration mode.) The working capacity will be represented in the sense of N. M. Sedyakin's resource. The service life in the concentration mode will be designated as $rq(x) = -\,ln(1 - Q(x))$. The total potential resource will be equal to $rq(\infty) = 2.053$. The worked-out resource is equal to $rq(60) = 1.719$. The residual resource in the concentration mode is $rqo = rq(\infty) - rq(60) = 0.334$. The recovery time of the resource in the chaos mode will be determined by solving equation

$$rw(x_0) = ln(1 + W(x_0) + rq(60) = 0\,.$$

To do this, we will find a solution to the operator:

$$x_0 = 60$$
$$Given$$
$$ln(1 + W(x_0) + 1.719 = 0(15)$$
$$Find(x_0) = 64.514.$$

Thus, the consumed resource is equal to:

$$rw(64{,}514) = -1.719.$$

Changing the sign of the resulting number to the opposite and summing it up with the residual resource, we get:

$$1.719 + 0.334 = 2.053.$$

This is the initial potential resource.

Conclusion

An attempt is presented to consider a person metrologist as a recoverable element of the metrological system. Two stages of its life cycle as a seasonal system are investigated. The first stage consists in the direct fulfillment of the functional duties of metrology. The second stage of the cycle is associated with the restoration of the metrologist's working capacity, his health, without which it is impossible to ensure the further working capacity of the metrological system and obtaining the target effect. If this stage is associated with the implementation of the concentration function in the corresponding environment (we will call it the concentration environment), then the second stage is associated with the opposing environment (we will call it the chaos environment) associated with the provision of the first environment. From a formal point of view, the environment of chaos is characterized by a probabilistic distribution function opposite to the concentration function of P. Levy, and is called by his name [15, 16].

More complex chaos processes are not covered in the article. Within the limits of restrictions, a quantitative relationship between the stages is established and a formal way of realizing this relationship is proposed. A simple example of the interaction of a concentration environment with a chaotic environment is given.

References

1. Antonovsky A. V., Bysyuk A. S. Professionalnoe zdorovye inzhenerov-metrologov: teoreticheskie i prikladnye aspekty [Professional Health of Metrology Engineers: Theoretical and Applied Aspects]. In: *Asmakovets E. S. (ed.) Zdorovye spetsialista: problemy i puti resheniya: Materialy IV zaochnoy Mezhdunarodnoy nauchno-prakticheskoy internet-konferentsii [Specialist's Health: Problems and Solutions: Materials of IV International Scientific and Practical Internet Conference], Omsk, Russia, Plovdiv, Bulgaria, October 01–31, 2013*. Omsk, Institute of Education Development of Omsk Region, 2013, Pp. 12–25. (In Russian)

2. Alekseev G. A. Podgotovka inzhenerov v oblasti standartizatsii [Training of Engineers in the Field of Standardization], *Sovremennoe obrazovanie: soderzhanie, tekhnologii, kachestvo: Materialy XVIII Mezhdunarodnoy nauchno-metodicheskoy konferentsii [Modern Education: Content, Technology, Quality: Proceedings of the XVIII International Scientific and Methodological Conference], Saint Petersburg, Russia, April 18, 2012. Volume 1*. Saint Petersburg, Saint Petersburg Electrotechnical University «LETI», 2012, Pp. 87–89. (In Russian)

3. Smagin V. A. Matematicheskaya model nadezhnosti funktsionirovaniya kollektiva operatorov i slozhnykh programmnykh kompleksov [Mathematical Model of Reliability of Collective Operative and Complex Program Complexes Functioning], *Informatsiya i kosmos [Information and Space]*, 2007, No. 1, Pp. 75–80. (In Russian)

4. Akhmedzhanov F. M., Krymsky V. G. Algoritm otsenki nadezhnosti cheloveka-operatora na osnove modifitsirovannoy metodiki HEART [Algorithm for Assessment of Human Operator Reliability Based on Modified HEART Methodology], *Elektrotekhnicheskie i informatsionnye kompleksy i sistemy [Electrical and Data Processing Facilities and Systems]*, 2019, Vol. 15, No.1, Pp. 60–69.
DOI: 10.17122/1999-5458-2019-15-1-60-69. (In Russian)

5. Ivanov O. V., Ivanov V. O. Method for Forecasting the Reliability of an External Pilot of a Remote Piloted Aerial System, *Vestnik Natsionalnogo aviatsionnogo universiteta [Proceedings of National Aviation University]*, 2019, No. 4 (81), Pp. 29–33. DOI: 10.18372/2306-1472.81.14598.

6. Yakovlev A. V. Obobshchennyy algoritm otsenki funktsionalnogo sostoyaniya organizma cheloveka–operatora [Generalized Algorithm for Assessing the Functional State of the Operator], *Nauchnaya sessiya GUAP: Sbornik dokladov nauchnoy sessii, posvyashchennoy Vsemirnomu dnyu aviatsii i kosmonavtiki [SUAI Scientific Session: Collection of Reports of the Scientific Session Dedicated to the World Day of Aviation and Cosmonautics], Saint Petersburg, Russia, April 08–12, 2019. Volume 2.* Saint Petersburg, Saint-Petersburg State University of Aerospace Instrumentation, 2019, Pp. 288–290. (In Russian)

7. Yakovlev A. V., Matitsin V. O. Analiz primenimosti sushchestvuyushchikh metodov obrabotki dannykh dlya otsenki funktsionalnogo sostoyaniya organizma cheloveka-operatora i prognozirovaniya ego rabotosposobnosti [Analysis of the Applicability of Data Processing Methods for Assessing the Functional State of the Operator and Predicting His Performance], *Nauchnaya sessiya GUAP: Sbornik dokladov nauchnoy sessii, posvyashchennoy Vsemirnomu dnyu aviatsii i kosmonavtiki [SUAI Scientific Session: Collection of Reports of the Scientific Session Dedicated to the World Day of Aviation and Cosmonautics], Saint Petersburg, Russia, April 08–12, 2019. Volume 2.* Saint Petersburg, Saint-Petersburg State University of Aerospace Instrumentation, 2019, Pp. 291–294. (In Russian)

8. Guchuk V. V., Desova A. A., Dorofeyuk A. A., Dorofeyuk Yu. A. Strukturno-kognitivnaya metodika otsenki rabotosposobnosti cheloveka-operatora po informatsii ego pulsogrammy [Structural and Cognitive Method of Performance Assessment of Human Operator on Information of His Pulse Rate], *Kognitivnyy analiz i upravlenie razvitiem situatsiy (CASC`2011): Mezhdunarodnaya nauchno-prakticheskaya Multikonferentsiya «Upravlenie bolshimi sistemami 2011»: Trudy IX Mezhdunarodnoy konferentsii [Cognitive Analysis and Situation Control (CASC`2011): International Scientific and Practical Multi–Conference «Management of Large Systems 2011»: Proceedings of the IX International Conference], Moscow, Russia, November 14–16, 2011*. Moscow, V. A. Trapeznikov Institute of Control Sciences of Russian Academy of Sciences, 2011, Pp. 202–205. (In Russian)

9. Baranova T. I., Berlov D. N., Chiligina Yu. A., et al. Novye sposoby otsenki nadezhnosti cheloveka-operatora [New Methods of Evaluation of the Human Operator Reliability], *Aviakosmicheskaya i ekologicheskaya meditsina [Aerospace and Environmental Medicine]*, 2004, Vol. 38, No. 6, Pp. 31–36. (In Russian)

10. Smagin V. A., Bubnov V. P., Sultonov Sh. Kh. Matematicheskie modeli dlya rascheta kolichestvennykh kharakteristik optimalnogo kvantovaniya informatsii [Mathematical models for calculation the quantitative characteristics of the optimal quantization of information], *Transportnye sistemy i tekhnologii [Transportation systems and technology]*, Vol. 7, No. 1, Pp. 46–58. DOI: 10.17816/transsyst20217146-58. (In Russian)

11. Smagin V. A. Srednyaya chastota otkazov apparatury pri nenadezhnykh elementakh zameny [Average Hardware Failure Rate with Unreliable Replacement Elements], *Izvestiya Akademii nauk SSSR. Tekhnicheskaya kibernetika [Proceedings of the Academy of Sciences of the USSR. Technical Cybernetics]*, 1975, No. 3, Pp. 118–120. (In Russian)

12. Gnedenko B. V., Dinich M., Nasr Yu. O nadezhnosti dublirovannoy sistemy s vosstanovleniem i profilakticheskim obsluzhivaniem [About Reliability of Duplicated System with Restoration and Preventive Maintenance], *Izvestiya Akademii nauk SSSR. Tekhnicheskaya kibernetika [Proceedings of the Academy of Sciences of the USSR. Technical Cybernetics]*, 1975, No. 1, Pp. 66–71. (In Russian)

13. Barzilovich E. Yu., Kashtanov V. A. Nekotorye matematicheskie voprosy teorii obsluzhivaniya slozhnykh system [Some mathematical issues of the theory of service of complex systems]. Moscow, Sovetskoe Radio Publishing House, 1971, 271 p.

14. Smagin V. A. Teoreticheskoe obobshchenie fizicheskogo printsipa nadezhnosti professora N. M. Sedyakina [Theoretical Generalisation of Physical Principle of Reliability by Professor N. M. Sedyakin], *Nadezhnost [Dependability]*, 2005, No. 1 (24), Pp. 3–13. (In Russian)

15. Smagin V. A., Shurygin E. M. Application of the Concentration Function in Fuzzy Sets Theory, *Intellektualnye tekhnologii na transporte [Intellectual Technologies on Transport]*, 2020, No. 1 (21), Pp. 16–23.

16. Smagin V. A., Novikov A. N. Function of Concentration function P. Levy and Its Application in the Theory of Fuzzy Sets L. Zadeh, *Modeli, sistemy, seti v ekonomike, tekhnike, prirode i obshchestve [Models, Systems, Networks in Economics, Technology, Nature and Society]*, 2020, No. 3 (35), Pp. 102–117.
DOI: 10.21685/2227-8486-2020-3-9. (In Russian)

DOI: 10.24412/2413-2527-2022-331-74-81

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Несколько замечаний о самом важном элементе метрологии — человеке

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Abstract. **В статье рассматривается человек как элемент метрологии. Функциональные обязанности и конкретные действия его не принимаются во внимание. Метролог представляется как двухфазная система, включающая два этапа жизненного цикла, первый цикл которой есть фаза концентрации — работа для получения эффекта, второй цикл — фаза хаоса, заключающаяся в восстановлении потраченных сил с целью продолжения первой фазы. Приводится формальная модель человека-метролога. Определяется оптимальная по коэффициенту готовности продолжительность межповерочного периода и среднее число ремонтов объекта за один год. При помощи реальной модели определяется средний возраст человека-оператора с точки зрения максимального коэффициента готовности, с учетом профилактических периодов и без них. В формальной и реальной моделях человека-оператора распределение времени жизни человека определяется экстремальным в статистике законом распределения Вейбулла. С формальной точки зрения среда хаоса характеризуется вероятностной функцией распределения, противоположной функции распределения среды концентрации по П. Леви. Определяется количественная связь между этапами и предлагается формальный путь реализации этой связи. Приведен простейший пример расчета восстановления исходного ресурса фазы концентрации.**

Keywords: **метролог, метрология, двухфазная система, среда концентрации, среда хаоса, средняя частота отказов, функция концентрации, обеспечение концентрации.**

Литература

1. Антоновский, А. В. Профессиональное здоровье инженеров-метрологов: теоретические и прикладные аспекты / А. В. Антоновский, А. С. Бысюк // Здоровье специалиста: проблемы и пути решения: Материалы IV заочной Международной научно-практической интернет-конференции (Омск, Россия, Пловдив, Болгария, 01–31 октября 2013 г.) / отв. ред. Е. С. Асмаковец. — Омск: Институт развития образования Омской области, 2013. — С. 12–25.

2. Алексеев, Г. А. Подготовка инженеров в области стандартизации // Современное образование: содержание, технологии, качество: Материалы XVIII Международной научно-методической конференции (Санкт-Петербург, Россия, 18 апреля 2012 г.): в 2 т. — Санкт-Петербург: ЛЭТИ, 2012. — Т. 1. — С. 87–89.

3. Смагин, В. А. Математическая модель надежности функционирования коллектива операторов и сложных программных комплексов // Информация и космос. 2007. № 1. С. 75–80.

4. Ахмеджанов, Ф. М. Алгоритм оценки надежности человека-оператора на основе модифицированной методики HEART / Ф. М. Ахмеджанов, В. Г. Крымский // Электротехнические и информационные комплексы и системы. 2019. Т. 15, № 1. С. 60–69.
DOI: 10.17122/1999-5458-2019-15-1-60-69.

5. Ivanov, O. V. Method for Forecasting the Reliability of an External Pilot of a Remote Piloted Aerial System / O. V. Ivanov, V. O. Ivanov // Вестник Национального авиационного университета. 2019. № 4 (81). С. 29–33.
DOI: 10.18372/2306-1472.81.14598.

6. Яковлев, А. В. Обобщенный алгоритм оценки функционального состояния организма человека–оператора // Научная сессия ГУАП: Сборник докладов научной сессии, посвященной Всемирному дню авиации и космонавтики (Санкт-Петербург, Россия, 08–12 апреля 2019 г.): в 3 ч. — Санкт-Петербург: ГУАП, 2019. — Ч. 2. — С. 288–290.

7. Яковлев, А. В. Анализ применимости существующих методов обработки данных для оценки функционального состояния организма человека-оператора и прогнозирования его работоспособности / А. В. Яковлев, В. О. Матыцин // Научная сессия ГУАП: Сборник докладов научной сессии, посвященной Всемирному дню авиации и космонавтики (Санкт-Петербург, Россия, 08–12 апреля 2019 г.): в 3 ч. — Санкт-Петербург: ГУАП, 2019. — Ч. 2. — С. 291–294.

8. Структурно-когнитивная методика оценки работоспособности человека-оператора по информации его пульсограммы / В. В. Гучук, А. А. Десова, А. А. Дорофеюк, Ю. А. Дорофеюк // Когнитивный анализ и управление развитием ситуаций (CASC`2011): Международная научно-практическая Мультиконференция «Управление большими системами–2011»: Труды IX Международной конференции (Москва, Россия, 14–16 ноября 2011 г.). — Москва: Институт проблем управления РАН, 2011. — С. 202–205.

9. Новые способы оценки надежности человека-оператора / Т. И. Баранова, Д. Н. Берлов, Ю. А. Чилигина, [и др.] // Авиакосмическая и экологическая медицина. 2004. Т. 38, № 6. С. 31–36.

10. Смагин, В. А. Математические модели для расчета количественных характеристик оптимального квантования информации / В. А. Смагин, В. П. Бубнов, Ш. Х. Султонов // Транспортные системы и технологии. 2021. Т. 7, № 1. С. 46–58. DOI: 10.17816/transsyst20217146-58.

11. Смагин, В. А. Средняя частота отказов аппаратуры при ненадежных элементах замены // Известия Академии наук СССР. Техническая кибернетика. 1975. № 3. С. 118–120.

12. Гнеденко, Б. В. О надежности дублированной системы с восстановлением и профилактическим обслуживанием / Б. В. Гнеденко, М. Динич, Ю. Наср // Известия Академии наук СССР. Техническая кибернетика. 1975. № 1. С. 66–71.

13. Барзилович, Е. Ю. Некоторые математические вопросы теории обслуживания сложных систем / Е. Ю. Барзилович, В. А. Каштанов. — Москва: Советское радио, 1971. — 271 с.

14. Смагин, В. А. Теоретическое обобщение физического принципа надежности профессора Н. М. Седякина // Надежность. 2005. № 1 (24). С. 3–13.

15. Smagin, V. A. Application of the Concentration Function in Fuzzy Sets Theory / V. A. Smagin, E. M. Shurygin // Интеллектуальные технологии на транспорте. 2020. № 1 (21). С. 16–23.

16. Смагин, В. А. Функция концентрации П. Леви и ее применение в теории нечетких множеств Л. Заде / В. А. Смагин, А. Н. Новиков // Модели, системы, сети в экономике, технике, природе и обществе. 2020. № 3 (35). С. 102–117. DOI: 10.21685/2227-8486-2020-3-9.