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SINGLE-FACTOR MODEL OF INFORMATION SECURITY THREATS OF THE AUTOMATED MANAGEMENT SYSTEM OF PRODUCTION OF HIGH-SPEED TELECOMMUNICATION DISTRIBUTED DATA TRANSFER SYSTEMS

Introduction

When developing information security systems of the automated control system (ACS) by the production of high-speed distributed data transmission paths, it is necessary to take into account the complex technological process of the whole life cycle of production, which, first of all, includes: software products of information technology supporting the adoption of operational decisions at various stages of the technological cycle, differences between the permittivity of distributed paths and the required values, which caused by technological instability of the manufacturing process, range of geometric dimensions of hard-shaped conductors, deviation of load parameters from nominal values etc. Management of such a complex production process requires enhanced information security of the automated control system: its protection against accidental and deliberate impacts of different nature.

Analysis of published data and problem definition

Analysis of the characteristics of automated control systems [1–3] for the production of high-speed distributed paths and the opinions of experts in this field showed that the dominant mathematical model of risk (risk factor) $\tilde{W}(y)$ and threat $\tilde{N}(y)$ can be represented in the form of stochastic equations

$$\tilde{N}(y) = N(y) + \Delta_1(y)\,, \tag{1}$$

$$\tilde{N}(y) = \frac{\tilde{W}'(y)}{2\tilde{W}(y)}\,, \quad N(y) = \frac{W(y)}{2W'(y)}, \tag{2}$$

where y is a variable that has the meaning of the current geometric coordinate of the information channel or another entity $W(y)$ — a deterministic function that characterizes the parameters of the distributed path in the absence of an ASM threat $\tilde{W}(y)$ — the random function of the distributed path (risk factor) when the threat is applied to the control system. Function

$$\Delta_1(y) = g(y)\Delta(y)\,, \tag{3}$$

determines the random process caused by the impact of the threat on the control system. At the same time, based on the technology of production and the opinions of experts, we can assume that the component of the threat $\Delta(y)$ is normal stationary white noise with a correlation function

$$K_\Delta(y_1, y_2) = \frac{N_0}{2}\delta(y_2 - y_1)\,, \tag{4}$$

and zero mathematical expectation

$$m\{\Delta\} = 0\,, \tag{5}$$

$g(y)$ — deterministic function determined by the production process, $g(y) \ge 0$.

From (2) and (3) we find the parameters of the distributed path in case of absence of an ASC threat

$$W(y) = A(y)X\,, \quad A(y) = \exp\left\{2\int_0^y N(y)dy\right\}, \tag{6}$$

$$X = \tilde{W}(0)\exp\left\{2\int_0^y \Delta_1(y)dy\right\}. \tag{7}$$

We represent the process X in the form

$$X = \exp\{2V\}\,, \tag{8}$$

Where

$$V = \int_0^y \Delta_1(y)dy + \frac{1}{2}\ln \tilde{W}(0) . \qquad (9)$$

From the foregoing we see that V is a Markov process with a diffusion coefficient

$$b(y) = \frac{N_0 g^2(y)}{2} , \qquad (10)$$

and zero drift coefficient [4–6]. Instead of the expression (9), we use another form of the notation

$$\frac{dV}{dy} = \Delta_1(y) , \quad V(0) = \lambda_0 = \frac{1}{2}\ln \tilde{W}(0) , \qquad (11)$$

$V(0) = \lambda_0$ — initial random value.

It follows from the relations (6), (8) that the statistical characteristics of the risk factor

$$\tilde{W}(y) = A(y)e^{2V} \qquad (12)$$

are completely determined by the Markov process V with some flow function $G(v, y)$

Determining the level of information security

First, we consider the threat in which the characteristics of the ACS are limiting and with further strengthening of the destructive effect, the parameters of the control system do not change. In this case, we can assume that the process V is between fixed boundaries. Without loss of generality, we assume that the boundaries are located in the cross sections $V = 0$ and $V = 2h$.

The probability density $P(v, y)$ of a random process $V(y)$ is found from the Fokker-Planck-Kolmogorov solution [6]:

$$\frac{\partial}{\partial y} P(v, y) = \frac{1}{2} b(y) \frac{\partial^2}{\partial V^2} P(v, y) . \qquad (13)$$

Separating the variables in this equation

$$P(v, y) = V(v)Y(y) , \qquad (14)$$

we find,

$$\frac{1}{b(y)Y(y)} \frac{\partial Y}{\partial y} = \frac{1}{2} \frac{1}{V(v)} \frac{\partial^2 V(v)}{\partial V^2} = -\lambda^2 , \qquad (15)$$

where λ^2 is a positive number. As result, we get

$$V'' + \lambda^2 V = 0 , \qquad (16)$$

$$Y' + \frac{\lambda^2}{2} b(y) Y = 0 . \qquad (17)$$

From this we find the function

$$Y(y) = Y(0)\exp\left\{ -\frac{1}{2}\lambda^2 \int_0^y b(y)dy \right\} . \qquad (18)$$

Suppose that the boundaries from which the process V is reflected are in sections $V = 0$, $V = 2h$. In these sections, the flow $G(v, y)$ must be zero [3].

Since the flow

$$G(v, y) = -\frac{1}{2}\frac{d}{dV}\left[b(y)P(v, y) \right], \qquad (19)$$

then for the probability density $P(v, y)$ the boundary conditions are satisfied

$$\frac{\partial}{\partial V} P(v, y)\Big|_{v=0} = \frac{\partial}{\partial V} P(v, y)\Big|_{v=2h} = 0 . \qquad (20)$$

Consequently

$$V'(0) = V'(2h) = 0 . \qquad (21)$$

Taking into account conditions (21), the solution of equation (16) can be written as a set of orthogonal normalized functions φ_k [6]:

$$\varphi_0(V) = \frac{1}{\sqrt{2h}} , \quad \varphi_k(V) = \frac{1}{\sqrt{h}} \cos \lambda_k V , \quad \lambda_k = \frac{k\pi}{2h} . \qquad (22)$$

Hence we find the general solution

$$P(v, y) = \sum_{k=0}^{\infty} C_k e^{-\frac{1}{2}\lambda_k^2 \int_0^y b(y)dy} \cos \lambda_k V . \qquad (23)$$

The constants C_k are found from the initial conditions. In particular, for a deterministic process V at the initial point $V(0) = \lambda_0$, we have

$$P(V, 0) = \delta(V - \lambda_0) , \qquad (24)$$

where $\delta(v)$ is the Dirac delta function.

Then, in accordance with the results of [5]

$$\delta(V - \lambda_0) = \sum_{k=0} \varphi_k(V)\varphi_k(0) \qquad (25)$$

we find

$$C_0 = \frac{1}{2h} , \quad C_k = \frac{1}{h} \cos k\pi \frac{\lambda_0}{2h} . \qquad (26)$$

Consequently,

$$P(v, y, \lambda_0) = \frac{1}{2h} + \frac{1}{h}\sum_{k=1}^{\infty} \cos\left[\frac{k\pi}{2h}\lambda_0 \right] \times \\ \times \cdot \cos\left[\frac{k\pi}{2h} v \right] \exp\left\{ -\frac{k^2\pi^2}{8h^2} \int_0^y b(y)dy \right\}, \qquad (27) \\ 0 < \lambda_0 < 2h , \quad 0 < v < 2h .$$

When considering the process in the region –*h*, *h*, we get

$$P_{-h,h}(v, y, \lambda_0) = \frac{1}{2h} + \\ + \frac{1}{h}\sum_{k=1}^{\infty} \cos\left[\frac{k\pi}{2h}(\lambda_0 + h) \right] \cos\left[\frac{k\pi}{2h}(v + h) \right] \exp + \left\{ -\frac{k^2\pi^2}{8h^2} \int_0^y b(y)dy \right\}, \qquad (28) \\ -h < \lambda_0 < h , \quad -h < v < h.$$

If we consider the process between arbitrary boundaries *c*, *d*, *c* < *d*, in the above expression it is necessary to go to the new variable [6]:

$$P_{c,d}(v, y, \lambda_0) = P_{-\frac{d-c}{2}, \frac{d-c}{2}}\left(v, y, \lambda_0 - \frac{c+d}{2} \right), \qquad (29) \\ c < \lambda_0 < d , \quad c < v < d .$$

If the initial condition $\lambda_0 = V(0)$ is a random variable, then according to the method of separation of variables [6] the general solution is:

$$P_{c,d}(v,y) = \int_c^d P_{c,d}(v,y,\lambda_0)P_0(\lambda_0)d\lambda_0, \quad (30)$$

$$c < v < d,$$

where $P_0(\lambda)$ is the probability density of the quantity λ_0.

Now consider the threat in which the characteristics of the control system change over time and lead to a temporary change in the process of managing the production of information transmission channels. In this case, the level of information security will be determined by the probability $q_{c,d}$ with which the process V does not exceed the limits of acceptable limits.

The probability density of a given process is determined by the direct Fokker-Planck-Kolmogorov equation [5; 6]:

$$\frac{\partial}{\partial y}\tilde{P}(v,y,\lambda_0) = \frac{1}{2}b(y)\frac{\partial^2}{\partial V^2}\tilde{P}(v,y,\lambda_0), \quad (31)$$

and the following condition [5]

$$\tilde{P}(c,y,\lambda_0) = \tilde{P}(d,y,\lambda_0) = 0. \quad (32)$$

It is easy to see that this condition is equivalent to observing equality on the boundaries of the domain *c*, *d*:

$$V(c) = V(d) = 0. \quad (33)$$

Separating the variables and assuming $c = -h,\ d = h$ for a nonrandom (deterministic) initial condition, we find the level of information security of the ACS:

$$q_{-h,h}(y,\lambda_0) = \frac{4}{\pi}\sum_{n=0}^{\infty}\frac{(-1)^n}{2n+1}\cos\left[\frac{(2n+1)\pi\lambda_0}{2h}\right]\exp\times$$
$$\times\left\{-\frac{(2n+1)^2\pi^2}{8h^2}\int_0^y b(y)dy\right\},$$
$$-h < \lambda_0 < h. \quad (34)$$

For an arbitrary region of boundaries *c*, *d*, according to [4], we have

$$q_{c,d}(y,\lambda_0) = q_{-\frac{d-c}{2},\frac{d-c}{2}}\left(y,\lambda_0 - \frac{c+d}{2}\right). \quad (35)$$

With a statistical initial condition with a probability density $P_0(\lambda_0)$, the level of information security is carried out taking into account (35). Intricate, according to theory fandom processes [4–6]

$$q_{c,d}(y) = \int_c^d q_{c,d}(y,\lambda_0)P_0(\lambda_0)d\lambda_0. \quad (36)$$

Example

Suppose that the threat to information security λ_0 in the interval c, d is evenly distributed

$$P_0(\lambda_0) = \frac{1}{d-c}. \quad (37)$$

From (34)–(36) we find the level of information security of the ACS:

$$q_{c,d}(y) = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{2n+1}\exp\left\{-\frac{(2n+1)^2\pi^2}{2(d-c)^2}\int_0^y b(y)dy\right\}. \quad (38)$$

Thus, the obtained results allow to estimate the level of information security of the automated production management system for high-speed distributed data transmission paths.

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On the basis of the theory of Markov processes, a model of threats to information security of an automated control system for the production of high-speed irregular distributed data transmission systems has been developed. Analytical expressions have been obtained, which allow us to assess the level of information security of the control system for the production of distributed information transmission channels.

Keywords: information security, threat model, production management system, distributed data transmission system, the theory of Markov processes.

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ОДНОФАКТОРНА МОДЕЛЬ ЗАПОБІГАННЯ ІНФОРМАЦІЙНОЇ БЕЗПЕКИ АВТОМАТИЗОВАНОЇ СИСТЕМИ УПРАВЛІННЯ ВИРОБНИЦТВОМ ВИСОКОШВИДКІСНИХ ТЕЛЕКОМУНІКАЦІЙНИХ РОЗПОДІЛЕНИХ СИСТЕМ ПЕРЕДАЧІ ДАНИХ

На основі основ теорії марковських процесів розроблено модель ризиків інформаційної безпеки автоматизованої системи управління виробництвом високошвидкісних нерегулярних розподілених систем передачі даних. Отримано аналітичні вирази, що дозволяють оцінити рівень інформаційної безпеки системи управління виробництвом розподілених каналів передачі інформації.

Ключові слова: інформаційна безпека, модель загроз, система управління виробництвом, розподілена система передачі даних, теорія марковських процесів.

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Однофакторная модель угроз информационной безопасности автоматизированной системы управления производством высокоскоростных телекоммуникационных распределенных систем передачи данных

На основе теории марковских процессов разработана модель угроз информационной безопасности автоматизированной системы управления производством высокоскоростных нерегулярных распределённых систем передачи данных. Получены аналитические выражения, позволяющие оценить уровень информационной безопасности системы управления производством распределённых каналов передачи информации.

Ключевые слова: информационная безопасность, модель угроз, система управления производством, распределённая система передачи данных, теория марковских процессов.

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