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The method of calculation for the period of checking utility systems

Метод расчета периода контроля оборудования инженерно-технических систем

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Abstract. The model and the procedure of optimization of the periods of control and scheduled maintenance in relation to the equipment of technical systems are considered. This approach is implemented on the basis of performance of a condition of a minimum of average losses of target use of the equipment. The specified losses are possible because of non-optimal frequency of control and prophylaxis of objects of technical networks. In article the approach used in the theory of information for minimization of decrease in informative value because of breaks by its transfer is considered. Feature of the offered approach is use of integer quantization of intercontrol intervals and the accounting of casual duration of operation of the equipment. Theoretical conclusions are illustrated by settlement examples.

Аннотация. Рассматривается модель и процедура оптимизации периодов контроля и профилактических мероприятий применительно к оборудованию инженерно-технических систем. Данный подход реализуется на основе выполнения условия минимума средних потерь целевого использования оборудования. Указанные потери возможны из-за неоптимальной периодичности контроля и профилактики элементов инженерно-технических систем. В статье рассматривается подход, используемый в теории информации для минимизации снижения ценности информации по причине перерывов при ее передаче. Особенностью предложенной подхода является использование целочисленного квантования межконтрольных интервалов и учет случайной продолжительности периодов эксплуатации оборудования. Теоретические выводы иллюстрируются расчетными примерами.

Introduction

Utility systems have a sufficient weight considering the efficient application of technological equipment as well as the use of buildings and constructions [1–3]. Therefore the necessity to provide their faultless operation takes a lot of attention. The requirements to operational systems are implemented at the early stages of designing buildings and constructions [4–8]. One of the most efficient means to provide the necessary level of reliability of the utility systems is the prevention of failures based

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on periodical check of their engineering status and carrying out the appropriate preventive maintenance during the operational period [9–11]. Hence the important part of operational security belongs to the matters considering the reasoning and construction of systems for checking the engineering status of utility systems [12–15]. At the same time the applied approaches are used in the most innovative fields of science and engineering [16–23].

A separate and rather complicated matter of introducing the monitoring of utility systems for buildings and constructions is the reasoning for the period of checking their elements and the following preventive maintenance. There are a number of approaches to solve the matter in question [24–35]. However, in the specified works reasoning of the required criteria for checks and preventive maintenance does not fully take account of the following peculiarities of utility systems: their ambiguous operational condition between the checks; discontinuity of the periods of checks and preventive maintenance, random periods of their operation between the prearranged repairs. In the present article these important assumptions are considered. It allows receiving results, more adequate for practice. Let us consider the physical representation of the given problem.

Methods

Physical interpretation of the model

Some considerably prolonged period of operation is considered. Such a period may be a regulatory period before the prearranged overhaul maintenance. Some divergence between the real and prescriptive periods of operation is expected to be possible. That happens due to a number of random factors and is consistent with the actual operation of facilities.

Let us suppose that during the operation of utility systems their operational condition can be determined only by means of checks. In a disabled state the facility cannot fulfill its main function. After receiving the relevant information about its condition, appropriate preventive maintenance is carried out. It includes the reconstruction of operational capability of the facility, if necessary. It is for that reason that regular checking of operational condition of the utility systems is introduced and put in practice. It is supposed that the facility has a limited reliability and can fail between two consecutive check measures. Therefore, two cases are possible. Firstly, the checking period may be determined too large, and the facility stays in a disabled condition for some time before it would be found out during the check. In this case there is a loss due to the utility system not performing its functions. Secondly, the checks may be carried out too often; therefore the facility would be operational before the checks. The operational loss stems from time loss for the excessive maintenance, as during this period the facility is also disabled. Hence it is essential to calculate such a value for the check and maintenance period, which would provide minimal average losses for the operational maintenance of utility systems in the given period of using the building (construction).

It is practical to consider the inter-check period as an integer value, divisible by some unit of time. Such a unit may be a workday or a work shift. This is more consistent with the reality of workload management for the staff of utility system's operational system, than the speculation about the continuity of this period. Let us now examine the mathematical interpretation of the given problem and the means to solve it.

Mathematical model 1 (basic model)

Suppose T is the operational time of a facility with a utility system. At the same time T is a random value and follows the distribution law $F(t)$. During the usage the operational condition of the facility is being checked. The period between consecutive check measures equals x. According to the abovementioned hypothesis x is an integer value of time units. The duration of checks and the following preventive maintenance equals c given units of time. Let us set p as the probability of faultless performance of the facility in a given time unit. Hence the random period of operation T has at the average K checks (and preventive maintenance). The chart in figure 1 shows the operational process in the graphical form.

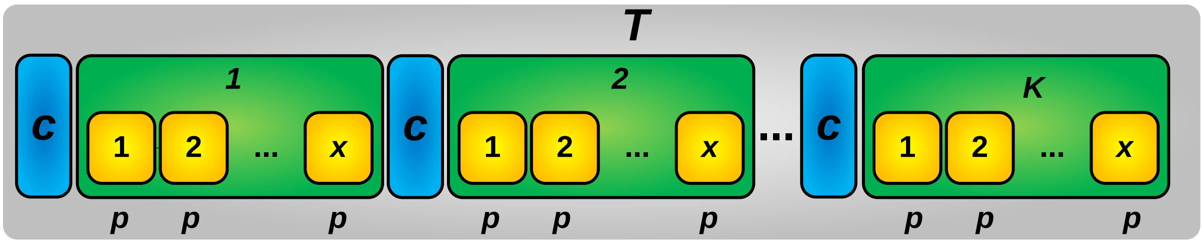

Figure 1. Graphical representation of operational process of a facility with a utility system

Let us use a well-known in information theory [36, 37] ratio for average losses $\Psi(x)$ of information in value x, determined by quantization of random period of time T. Under quantization we mean the choice of an integer value for x. For $\Psi(x)$ the expression takes the following form:

$$\Psi(x) = (x+c)\int_0^\infty \left(\left\lfloor \frac{z}{x} \right\rfloor + 1 \right) dF(z), \quad (1)$$

where z – an integration variable, characterizes operation interval size; record $\lfloor A \rfloor$ is Antje of number A.

However, the equation (1) does not take into account the possible failure of a facility during any time unit, as well as during the whole inter-check period (quantum). Let us introduce this clause in the following way. As the value p as the probability of faultless performance of a facility in a given time unit is known, then the probability $P(x)$ of its faultless performance in the period x is determined by the equation:

$$P(x) = \prod_{i=1}^{x} p = p^x \quad (2)$$

Clearly, considering equation (2), the mathematical expectancy $\overline{x}$ of duration of the period, when the facility works without fault in scope of the inter-check period x, is determined by the equation

$$\overline{x} = x \cdot p^x \quad (3)$$

Now let us insert equation (3) into formula (1). Besides, the value of average losses during the application of the check system is denoted as $M(x,p)$. As a result, the formula is written as following:

$$M(x,p) = (xp^x + c)\int_0^\infty \left(\left\lfloor \frac{z}{xp^x} \right\rfloor + 1 \right) dF(z). \quad (4)$$

Now it is necessary to find such a value of x, which allows the minimal overall loss $M(x,p)$ at the checks and maintenance of the facility with the utility system in the operational period T. At the same time one should take into consideration that x is a discrete value. The problem in question is solved comparatively easily via the method of computational analysis by means of the contemporary mathematical packages.

Mathematical model 2 (model for two check systems)

The base model, determined by the equation (4), does not account for a reliability index of checking the operational condition of utility systems. In practice, different ways of checking are applied with different probability of accurate determination of the operational condition of the facility. To take this peculiarity into consideration, let us analyze the following example.

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Two independent check systems simultaneously determine the operational condition of a facility in a time period x. The reliability p_k of checks for each of the given systems will be determined via the probability of finding a failure. Therefore the reliability p_{s2} of estimating the operational condition of the facility by both check systems is defined as $p_k{}^2$. Time, spent on checking the operational capacity of the facility, is constant and equals c. Time for reconstructing a disabled facility is constant and equals c_B.

It is required to find the value of check period x^*, which allows the minimal mathematical expectancy of time losses during the operation, provided that the value of probability p_{s2} of faultless performance of the checked facility is not less than the given one.

The formula for the value $M(x, p, p_{s2})$ of the average losses in the operational period T considering the condition in question is written as following:

$$M(x, p, p_{S2}) = \left(xp^X + c\,p_{S2} + c_B(1 - p_{S2})\right)\int_0^\infty \left(\left\lfloor \frac{z}{xp^X} \right\rfloor + 1\right) dF(z), \tag{5}$$

where $p_{s2} = p_k^2$.

Minimal value for $M(x, p, p_{s2})$ from the formula (4) is calculated by solving the given nonlinear problem.

Mathematical model 3 (model for three check systems)

Let us now introduce the following condition. The check of operational condition of a utility system is performed by three independent check systems. In addition, the results provided by these systems are combined in a majoritary way. Thus the reliability p_{s3} of the right estimation of the operational condition of the facility is determined by concurrence either of all three check systems or of two out of three. In such a case the probability p_{s3} to accurately estimate the performance of the equipment can be calculated with the following formula:

$$p_{s3} = 3p_k{}^2 - 2p_k{}^3. \tag{6}$$

The equation for the value $M(x, p, p_{s3})$ of average losses in operational period T considering the given condition is written as following:

$$M(x, p, p_{S3}) = \left(xp^X + c\,p_{S3} + c_B(1 - p_{S3})\right)\int_0^\infty \left(\left\lfloor \frac{z}{xp^X} \right\rfloor + 1\right) dF(z). \tag{7}$$

The minimal value for $M(x, p, p_{mc})$ from the formula (7) can be calculated.

Results and Discussion

Let us explain the proposed approach to the optimization of the period of checking the utility systems with a theoretical examples.

Theoretical example 1 for mathematical model 1.

Given data.

Time c, necessary for performing the checks and preventive maintenance at the facility with the utility system, is 5 time units. Random period T of the anticipated time of facility operation is determined by the normal probability law with the expectancy m = 100 time units and the average squared displacement σ = 20 time units.

Required:

Find the value of check period x^*, which achieves the minimal value of average overall losses $M(x)$ at the check of the utility system in operational period T for the following values of probability p of faultless performance of the facility in a time unit: 0,999; 0,95 and 0,90.

Solution:

To solve the problem let us use the equation (4). For this purpose for each value of p probability it is necessary to calculate $M(x)$ for an allowed value area of x

The results of calculations, carried out by means of MathCad package, are shown in the graphs in figure 2. In this case the graph $M_0(x)$ is corresponding to the calculated dependence of $M(x)$ at p = 0,999; and the graphs $M_1(x)$ and $M_2(x)$ at p, that equals 0,95 и 0,90 accordingly.

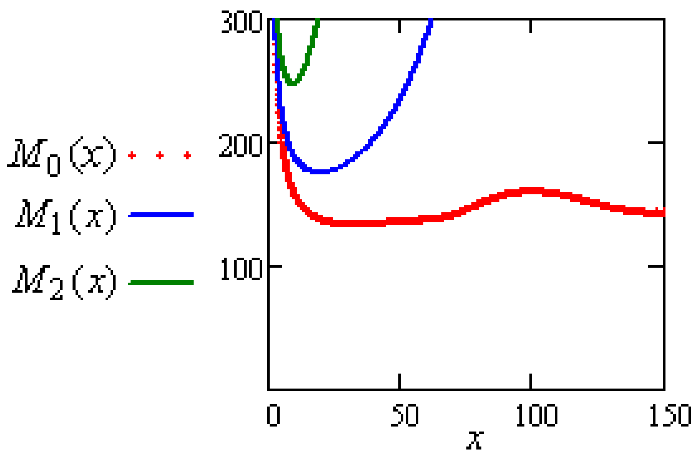

Figure 2. Graphs of functions $M_0(x)$, $M_1(x)$ and $M_2(x)$

Optimal values x^* of the time period x between consecutive checks and preventive maintenance of the utility system for the functions $M_0(x)$, $M_1(x)$ and $M_2(x)$ are 34, 20 and 9 time units accordingly. The corresponding minimal values of $M(x)$ expectancy for the probability p, which equals 0,999; 0,95 and 0,90 (functions $M_0(x)$, $M_1(x)$ и $M_2(x)$) are therefore equal to 134, 176 and 248 time units.

Graph analysis in picture 2 allows the following conclusions:

1) The more reliable is the facility of a utility system (higher probability p of faultless performance), the longer should be the period of checking its operation;

2) Improving the reliability of equipment significantly lowers the overall losses at its operation.

The abovementioned conclusions comply with the intuitive properties of the correlations in question. That also allows the inference that the model represented is conforming to the processes under examination.

Figures 3–6 present the calculated results of auxiliary parameters of the given mathematical model. On the abscissa axis of the first three pictures is plotted the value of the mathematical model. Figure 3 shows the graphs of variations for minimal $M(x, p)$ and optimal periods x^* of checking the operational condition of the utility system. Figure 4 describes the dependence of the second initial moment of check period $\alpha(p)$ on the probability p. Figure 5 presents the graphs of standard deviation of $\Xi(p)$, variability index $\eta(p)$ (magnified by 200 for descriptive purposes) and optimal value $K(p)$ of checks in operational period T depending on the value of p. Figure 6 shows the probability density

$g_i(u)$ for random values u of operational period of a utility system, i = 0, 1, 2 for the base values of probability p of faultless performance of the facility in a time unit.

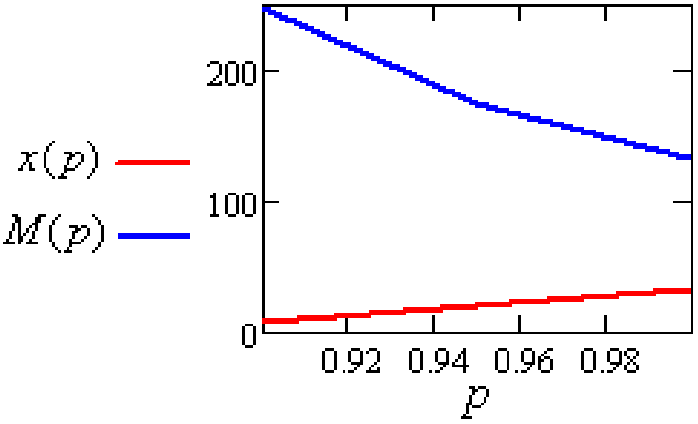

Figure 3. Graphs of variations for $M(x,p)$ and x^* of the facility p

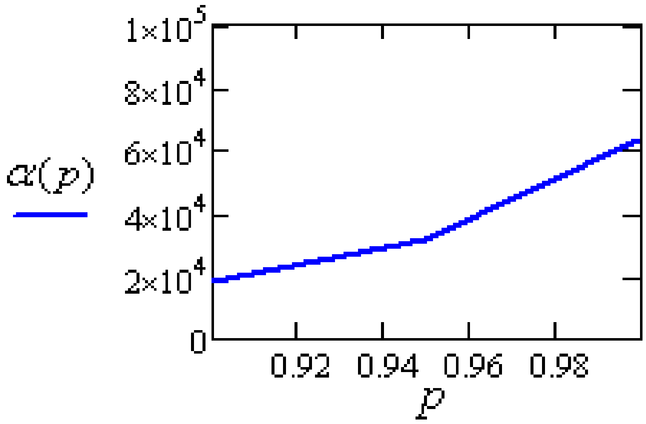

Figure 4. Dependence of the second initial moment of check period for operational condition of the facility p

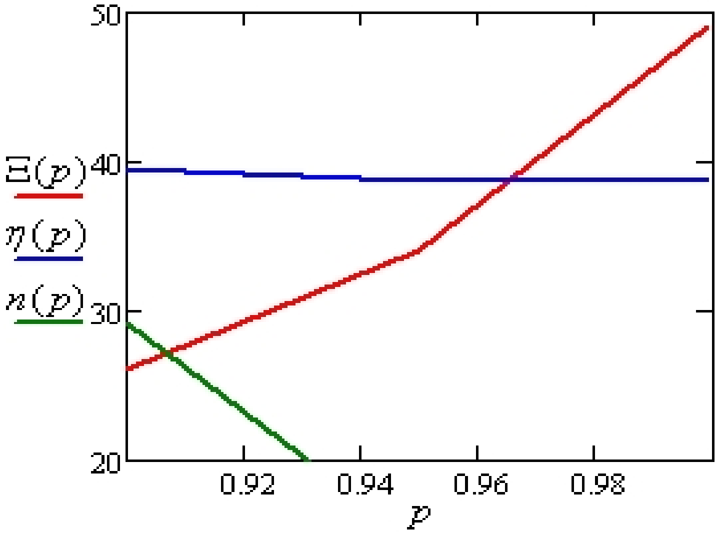

Figure 5. Graphs of standard deviation, variability index, and optimal value of checks

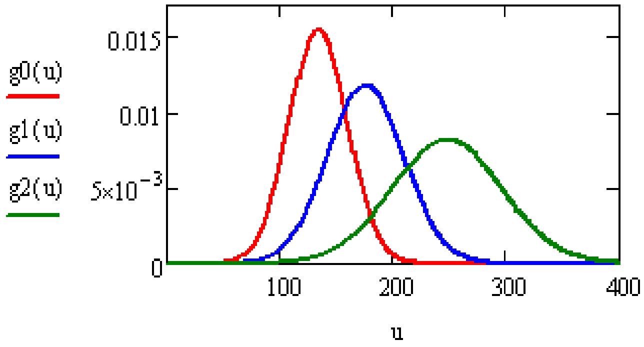

Figure 6. Probability density for random values of operational period of a utility system

Theoretical example 2 for mathematical model 2.

Given data:

Minimal value of $M(x, p, p_{s2})$ can be found at x_0. The duration c of checking the operational condition of the utility system equals 5 time units. The duration c_B of the maintenance equals 100 time units. Random interval T of the estimated time of facility operation is determined by the normal probability law with the mathematical expectancy m = 100 time units and the average squared displacement σ =20 time units. The probability p of the faultless performance of the facility in a time unit equals 0.75.

Required:

Find the value of check period duration x^*, which achieves the minimal value of average overall losses $M(x, p, p_{s2})$ at the check of the utility system in operational period T for the following values of probability p_k of finding a failure at the facility in a time unit: 0.999; 0.75 and 0.50.

Solution:

To solve the problem let us use equation (5). Thus for each value of p_k probability it is necessary to calculate $M(x, p, p_{s2})$ for an allowed area of x.

The results of calculations, carried out by means of MathCad package, are shown in the graphs in figure 7. In this case the graphs of $MT_0(x)$, $MT_1(x)$, $MT_2(x)$ functions are corresponding to the calculated dependence of $M(x, p, p_{s2})$ at p = 0.75 and p_k = 0.999; 0.75; 0.5 accordingly.

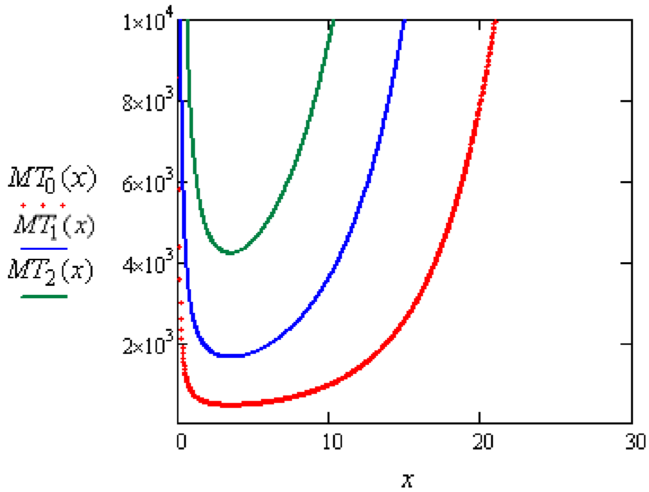

Figure 7. Graphs of $MT_0(x)$, $MT_1(x)$, $MT_2(x)$ functions

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Table 1 shows the calculations of $M(x_0)$ – minimal value of average costs for checks and maintenance of the facility in operational period T and x_0 - optimal value of check period for the facility.

Table 1. Results of calculations

Number of model	Parameters	
	$M(x_0)$	x_0
$MT_0(x)$	513	2
$MT_1(x)$	3 803	3
$MT_2(x)$	6 163	4

Theoretical example 3 for mathematical model 3.

Given data:

The data is the same as in example 2. However, three check systems are used.

Required:

Find the value of check period duration x^*, which achieves the minimal value of average overall losses $M(x, p, p_{s3})$ at the check of the utility system in operational period T for the following values of probability p_k of finding a failure at the facility: 0.999; 0.75 and 0.50.

Solution:

To solve the problem let us use the equation (7). Thus for each value of probability p_k it is necessary to calculate $M(x, p, p_{s3})$ for an allowed area of x.

The results of calculations, carried out by means of MathCad package, are shown in the graphs in figure 8. The graphs of $MT_0(x)$, $MT_1(x)$, $MT_2(x)$ functions are corresponding to the calculated dependence of $M(x, p, p_{s3})$ at p = 0.75 and p_k = 0.999; 0.75; 0.5 accordingly.

Figure 8 shows the graphs of $MT_0(x)$, $MT_1(x)$, $MT_2(x)$ functions at p = 0,75 and p_k =0.999; 0.75; 0.5.

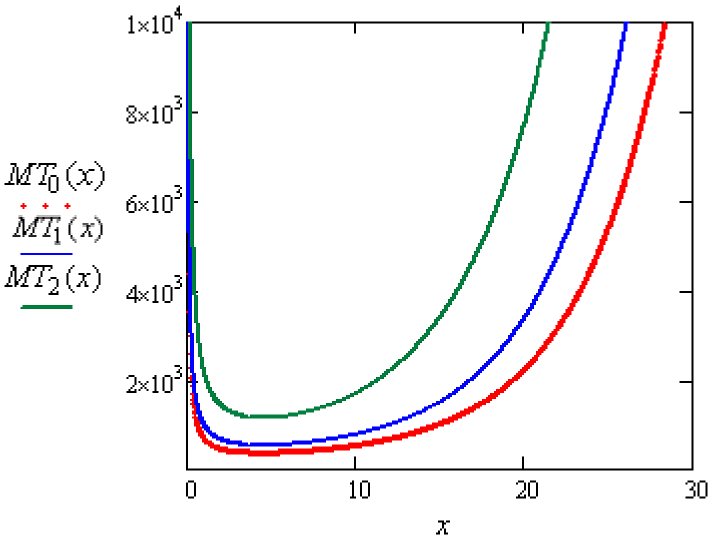

Figure 8. Graphs of $MT_0(x)$, $MT_1(x)$, $MT_2(x)$ functions

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Table 2, similar to table 1, presents the results of calculations.

Table 2. Results of calculations

Number of model	Parameters	
	$M(x_0)$	x_0
$MT_0(x)$	498	2
$MT_1(x)$	1 678	3
$MT_2(x)$	4 275	4

Examination of the calculations shows that the majoritary approach is quite efficient for improving the reliability of checking the operational condition of utility systems.

Conclusion

The present work is solving the problem of developing an approach to reasoning an optimal period of checking utility systems. Conducted studies of the results, offered in article allow to receive following conclusions.

1. Optimization of the periods of control on a set of discrete numbers is more adequate to real practice of planning of prevention of utility systems in comparison with the known models.

2. The offered models are based on an assumption about accident of size of an interval of operation of utility systems. It allows to take influence of various factors on work of systems of operation of buildings and constructions into account, which lead to change of the planning between-repairs periods (fig. 2, 7, 8), and also to estimate the accuracy of the received results (Figs. 3–6).

3. In the offered models indicators of non-failure operation of objects of utility systems are entered into consideration (Figs. 2, 7, 8). In the known information models these indicators aren't considered.

4. The offered models consider veracity of operation of control systems of various configuration (Figs. 7, 8, Tables 1, 2). It allows to prove the choice of the corresponding control system and to correct prevention intervals.

The obtained results may be used in the reasoning of advanced utility systems of buildings and constructions, as well as in rationalization of the present utility systems.

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