THE ANALYSIS OF USEFULNESS OF OPERATIONAL POTENTIAL CONSUMPTION MODELS TO CONTROL COMPLEX TECHNICAL SYSTEMS MAINTENANCE

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Abstract

The carried on studies consider a crucial complex exploitation system of strategic importance from the national economy point of view. In case of such class of systems, operation and service processes should be executed according to maintenance strategy named maintenance strategy by controlled consumption of operational potential. Thanks to it, optimal amount of operational potential included in the system can be transformed into the effect of the system operation. To execute exploitation processes according to the mentioned above strategy a model of operational potential consumption process should be implemented. The model estimates amount of operational potential consumed during exploitation processes execution. During carried out studies, models used to manage exploitation systems maintenance were identified. In the paper, identified models are divided into groups of analytical, stochastic and system ones. Next, usefulness of each group of models to control processes of exploitation phase of crucial complex strategic exploitation systems was discussed. As a result it was stated that it is necessary to create the universal system model, which can project influence of forcing factors on a state of technical object being a part of considered class of technical systems. In the paper, a structure of created universal system model was also proposed. This model was created by implementation the artificial intelligence techniques in form of genetic algorithms and fuzzy logic. Fuzzy logic was used to model approximate character of model input data and genetic algorithms were used to optimize a value of model output data.

Keywords: *Exploitation, Maintenance management, Operational potential, Modelling*

1. Introduction

In the exploitation phase the main groups of executed processes are operation and services ones [10]. In order to avoid the exploitation conflict between the activities which origin from limited access to technical object [27], those processes are managed together by introduction of exploitation strategies. In case of crucial, complex exploitation systems of strategic importance [7] only some exploitation strategies could be used. This is due the fact, that not planned immobilizing of that system can bring huge economic, human or social losses or risk of such losses [3]. As a result of carried out studies [20] it was stated that at the start moment of the service processes there is an amount of operational potential not transformed into the effect of the system operation. This situation is independent from a type of exploitation strategy (one from the set of strategies that can be used in case of crucial objects). In case of the technical object exchange, this amount is lost and the quality of operation of exploitation system is decreased. Controlling the intensity of the operational potential consumption it is possible to minimize the amount of operational potential not transformed into the effect of the system operation.

To execute exploitation processes of complex technical system in a rational way the model of the operational potential consumption should be used. Applicable model should allow the control of operational potential consumption process. In order to do that, the state of technical system at the t_2-Δt moment should be identified. The forecast of the state for t_2 moment should be also created. Additionally, the course of the function of operational potential consumption in the Δt period of time should be established. It should be done on the basis of the knowledge of time courses of forcing factors.

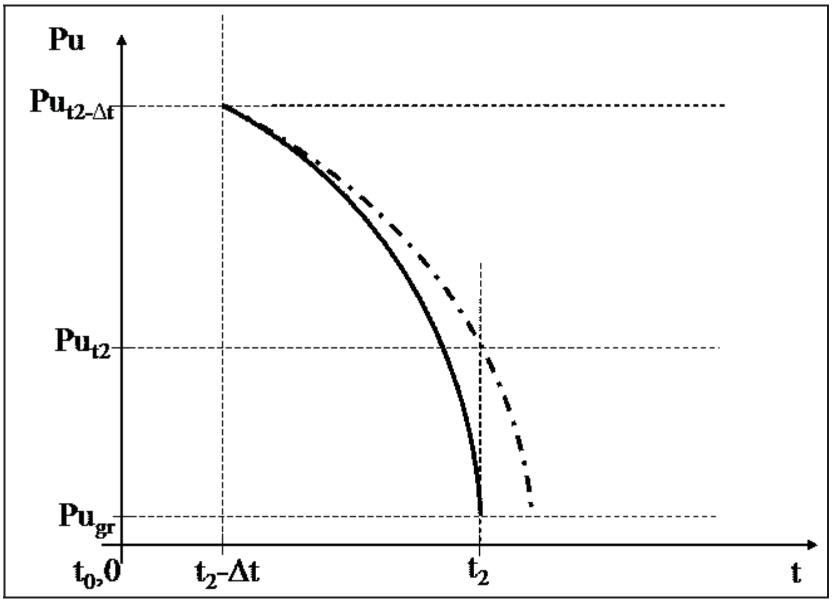

Fig. 1. The process of the operational potential consumption in the time scale - the strategy by controlled consumption of operational potential

According to each considered exploitation strategy, the service processes start at the moment of time fixed in advance. This is because the fact that in case of crucial objects it is necessary to execute periodical technical maintenance. It is regulated by law and controlled by organizations established specially for this purpose [22, 23, 26]. So, this is a situation when an operational potential amount for t_2-Δt moment of time is identified and the period Δt of operation processes execution is known (dashed line Fig. 1). Applying the characterized model will thus consists in controlling of operational potential consumption (by means of control of intensity of operation processes) in such a way that specified amount of operational potential could be transformed into the result of system operating in an fixed period of time avoiding the technical object damage (Fig. 1 – solid curve). Such strategy is named exploitation strategy by controlled consumption of operational potential.

In order to execute exploitation processes according to presented strategy the model of operational potential consumption should be used. The analysis of existing models used for control operating processes was done in order to define their usability for complex, crucial systems.

2. Analysis of the models used to control the exploitation processes

The first group of models used to exploitation processes control is analytical models group. These models describe dependencies between the wearing processes of machinery elements and time courses of forcing factors. Description of wearing degree of machinery elements identifies the technical state of the object and consequently the amount of operational potential included in it. To formulate an analytical model it is necessary to know theoretical description of the wearing processes, which takes place in the examined technical objects. Unfortunately, the knowledge about the examined objects is often inaccurate and insufficient to create an analytical model [13]. As a result of the studies carried out in a field of not controlled exploitation processes many types of tribological [11, 18], corrosive [2] and erosion wearing have been theoretically described. Also type of wearing caused by heat load and chemical factors have been described. Unfortunately, still some types of wearing processes are not described in a quantitative way. These types of processes are brittle cracking and wearing in a condition of high temperature and pressure [5] as well as cavitational wearing [6]. Therefore analytical models of the machinery elements wearing are created for the selected groups of elements [19] and for particular exploitation states and wearing types [24]. Additionally, the necessary condition of precise identification of technical object state by analytical models is familiarity with exact values of forcing factors having an influence on object during the operation process. In case of technical objects exploitated in industrial systems exact values of forcing factors very often are not known.

Analytical models, which describe dependencies between wearing process of machinery elements and time courses of forcing factors, are used in case of technical systems composed of objects of similar construction and low-complex influence of forcing factors. Therefore in case of complex technical objects, changes of operational potential quantity could not be given with proper accuracy thanks to analytical models use.

In a field of machinery maintenance the research are carried out with the purpose of using the decision models of exploitation control process [9, 17]. The execution of exploitation processes is described by finite number of states and finite number of actions. The actions take place when an object is in a specified state. They influence on time the object remains unchanged (at the same state) and on probability of changing the current status. Analysing these states and actions, the decision model chooses an optimal variant of technical objects exploitation execution. The research assumes that changes of the state of technical objects happen in a specified, digitized moments and that the consecutive object state depends only on the current state. This way the digitization of technical system states' space is introduced. It is equivalent to digitization of operational potential consumption expressed as a function of forcing factors time courses. In this case the digitization can be defined as a transformation of continuous course into digitized one. This is called quantization [14], in a field of values and time. Quantization of runtime is called sampling.

If we want to express the operational potential consumption process accurate enough to control its dynamic in implemented digitization, the sampling frequency, according to Shanon theorem [1] should be at least two times higher than Nyquist frequency, which is equal to the highest frequency included in a spectrum of time course. It generates large quantity of identified technical object states. Therefore the description of the process of changes the operational potential amount become very complicated. In the research the process of changes of the technical objects status is modelled as Semi-Markov one [8, 12] with use of income function [15, 21]. Implementation of the models with probabilistic description of their operation moves a domain of consideration into not organized complexity where diversification and dispersion of elements is big enough to obtain the necessary accuracy of a prediction [28].

Describing the methods that could be used for modelling the operational potential consumption process by means of analytical or probabilistic models, the limitations of their use is defined. On a diagram (Fig. 2) the ranges of application for each group of described above models are presented. It's easy to notice the area of complex technical system where it is not possible to control the process of operational potential consumption using analytical or stochastic models.

For complex technical objects belonging to distinguished range of systems space the potential-effect model of operation process has been worked out. This method describes in general operational potential resource and its transformation into the effect of the system operation [4]. It is possible to identify the technical system state on a potential – effect plane. Unfortunately, presented method does not provide a function that could express the system state into the space of its features. It also does not connect the system state modification with a time course of forcing factors. That is the reason why the method is not enough for determining the technical system state at the t_2 start time of the service processes on the basis of state at $t_2 - \Delta t$ moment and a time course of forcing factors within the time range $(t_2 - \Delta t,\ t_2)$. Additionally, the analyzed theory makes an assumption that the efficiency of the operational potential transformation into the effect of the object operation is constant. The constant efficiency of the transformation assumes constant velocity of operational potential consumption in the complex technical object. Therefore it is not possible to control the dynamics of the operational potential consumption process using the potential – effect model.

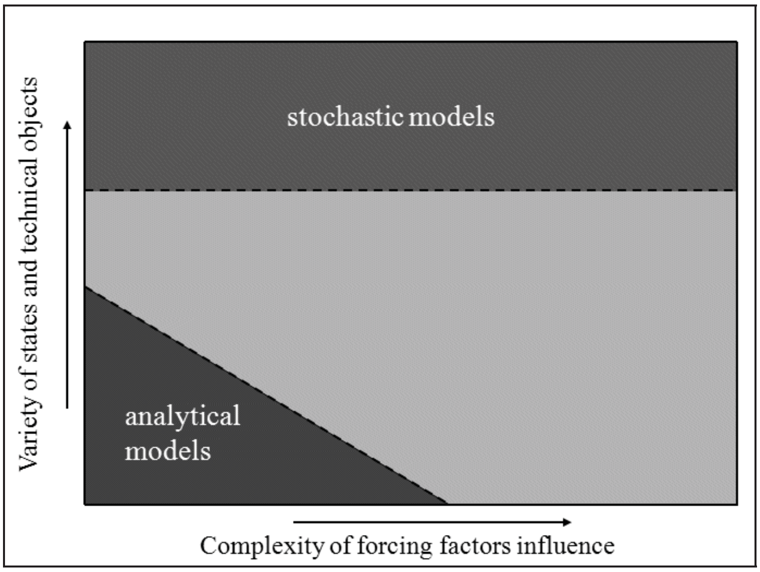

Fig. 2. The plane of technical systems distinguished on the basis of possibility of the operational potential consumption process modelling

On the basis of the presented analysis of the research carried out in the area of the exploitation processes' modelling it was stated that, at the present time, there is no mathematical model of operational potential consumption process that can be used to control the dynamics of this process for the specified class of technical systems.

3. Structure of a universal model of operational potential consumption process

Control of run and dynamics of the operational potential consumption process can be expressed as a change of trajectory of system operating point during the execution of the process. Because the dimensions of technical system state space are its cardinal features thus changes of trajectory of system operating point is expressed as changes of values of its cardinal features. That is why modification the trajectory of the system operating point is equivalent to controlling the changes of values of the system cardinal features and the velocity of theses changes.

Changes of the values of the system cardinal features take place during operating processes execution owing to forcing factors influence. Forcing factors are divided into two basic classes: dependent on system operation and independent from system operation [29]. Affection of the first class is a result of execution the operating process whereas the second class characterizes the influence of surroundings on the system [16]. The level of influence by the forcing factors depends on the method of operating process execution as well as intensity of surroundings influence on the system. Assuming, the surroundings influence on the system as independent value, we can state, that a task of control the changes and velocity of changes of system cardinal features could be accomplished by controlling the intensity of operating processes.

Operating process is described by its parameters values. Thus, the intensity of the realization of this process is determined by time courses of operational parameters values. Therefore, in order to control the dynamics of operational potential consumption it is necessary to create the model of this process. This model should represent changes in amount of operational potential included in the system as a function of time courses of operational parameters of the processes.

During the studies, a mathematical model of operational potential consumption process is considered. The model is based on general formula, which expresses changes of operational potential amount included in the object as a function of forcing factors time courses (1)

$$Pu(t_1) = Pu(t_2) + \Delta Pu(c_z^1(\Delta t_u), c_z^2(\Delta t_u), \ldots, c_z^i(\Delta t_u), c_{nz}^1(\Delta t_u), c_{nz}^2(\Delta t_u), \ldots, c_{nz}^j(\Delta t_u), \quad (1)$$

where:

$Pu(t_1)$ - the amount of operational potential at the t_1,

$Pu(t_2)$ - the amount of operational potential at the t_2,

ΔPu - change of operational potential amount,

$c_z^i(\Delta t_u)$ - time course of forcing factor no i that depends on operation of technical object within time period Δt_u,

$c_{nz}^j(\Delta t_u)$ - time course of forcing factor no j that is independent from operation of technical object within time period Δt_u.

Designed model, on the basis of time courses of operational parameters, will estimate the levels of forcing factors influence on the system state. Next, based on the levels of the forcing factors influence, the changes of system cardinal features will be identified. Finally, based on changes of values of system cardinal features, the change in amount of operation potential included in the system will be specified (2).

$$M\Delta P : (pe_1(t)\Big|_{t_1}^{t_2}, \cdots, pe_m(t)\Big|_{t_1}^{t_2}) \rightarrow (c_{z1}(t)\Big|_{t_1}^{t_2}, \cdots, c_{zn}(t)\Big|_{t_1}^{t_2}, c_{nz1}(t)\Big|_{t_1}^{t_2}, \cdots, c_{nzr}(t)\Big|_{t_1}^{t_2}) \rightarrow$$
$$(\Delta x_1, \cdots, \Delta x_s) \rightarrow \Delta P_u, \quad (2)$$

where:

$M\Delta P$ - the model of operational potential consumption,

pe_i - operational parameter no i where i=1,...,m,

c_{zj} - forcing factor no j that depends on a system operation j=1,...,n,

c_{nzk} - forcing factor no k that is independent from a system operation k=1,...,r,

Δx_l - change of the value of the system cardinal feature no l where l=1,...,s.

Application of described model will be used for defining the technical system state at the t_2 moment on the basis of technical system state at the t_1 moment and time courses of operational parameters within time period $[t_1,\ t_2]$ (3)

$$(s(t_1), pe_1(t)\Big|_{t_1}^{t_2}, \cdots, pe_m(t)\Big|_{t_1}^{t_2}) \xrightarrow{M\Delta P} s(t_2). \quad (3)$$

To define time courses of operational parameters in the time period $[t_1,\ t_2]$ on the basis of technical system state at t_1 moment and expected system state at t_2 moment it is necessary to create an inverse model of operational potential consumption (4)

$$(s(t_1), s(t_2)) \xrightarrow{M^{-1}\Delta P} pe_1(t)\Big|_{t_1}^{t_2}, \cdots, pe_m(t)\Big|_{t_1}^{t_2}, \quad (4)$$

where:

$M^{-1}\Delta P$ - inverse model of operational potential consumption.

For both model and inverse model the input parameter is the system state at the initial t_1 moment of the process. It comes from Markov properties of a system state [25]. It means that system state at the t_2 moment is uniquely defined by the state at the t_1 moment and known input values for $t \subset [t_1, t_2]$ and is independent from the system state and inputs before the t_1 moment.

6. Conclusions

On the basis of the considerations presented in the paper the following conclusions were formulated:

- the minimisation of the amount of an operational potential not transformed into the effect of the system operation can be accomplished thanks to control of intensity of operational potential consumption process,
- the implementation of the maintenance strategy by controlled consumption of operational potential consists in controlling the dynamics of an operational potential consumption process by modification the intensity of operating processes in order to transform all identified amount of the operational potential into the effect of the system operation in the determined period of time avoiding the technical object failure,
- for realization the operating processes according to strategy by controlled consumption of operational potential it is necessary to use mathematical model of this process,
- analytical models that describe dependencies between machines parts wearing processes and time courses of forcing factors are used in case of technical systems, which consist of objects of similar construction and simple function of forcing factors influence. Therefore in case of complex technical objects changes in amount of operational potential could not be identified accurate enough by means of analytical models,
- implementing models with probabilistic method of operation moves the considerations to space of non-organized complexity where diversification and dispersion is high enough to obtain the necessary accuracy of predictions,
- it is not possible to control dynamics of operational potential consumption process by means of potential – effect model of operating process because of assumption about constant efficiency of the operational potential transformation into the effect of a system operation,
- there is no mathematical model of operational potential consumption that can be used to control the dynamics of operational potential consumption process in case of complex, crucial exploitation systems,
- designed model, on the basis of time courses of operational parameters, will estimate the levels of forcing factors influence on the system state. Next, based on the levels of the forcing factors influence, the changes of system cardinal features will be identified. Finally, based on changes of values of the system cardinal features, the change in amount of operation potential included in the system will be specified.

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