MAINTENANCE STRATEGY BY CONTROLLED CONSUMPTION OF OPERATIONAL POTENTIAL

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Abstract

The main groups of processes executed during exploitation phase of a machine are service and operating processes. The main objective of the operating processes is a generation of machine's operation effects. While an objective of the service processes is a reconstruction of object's exploitation properties, which are necessary to proper machine operation. In the case of complex, crucial exploitation systems the service and operating processes can't be performed in the same time. Then, it is necessary to implement adequate strategy of exploitation processes execution. According to carried out studies it was stated that the service and operating processes could be expressed as functions of an operational potential amount included in an exploitation system. It was also stated that execution of the exploitation processes according to the optimal maintenance strategy guaranties minimisation of an operational potential amount untransformed to effects of the exploitation system operation. In the case of the analysed class of complex, crucial, strategic exploitation systems the start moment of the service processes is defined a several months in advance. In this paper, the maintenance strategy by controlled consumption of operational potential is presented. The strategy is formulated as an optimal method of exploitation processes execution. It is especially useful in the case of complex systems where it should be make a most of the operational potential.

Keywords: *Exploitation, Maintenance management, Operational potential*

1. Introduction

Exploitation can be defined as a sequence of random events, which expresses changes of an operation point of objects. Therefore, it can be also treated as a controlled random process of object's operational potential consumption. The most important groups of processes performed in an exploitation system are operating and service processes [1-3].

During the operating processes the operational potential of an object is transformed to effects of the exploitation system operation. Simultaneously, the influence of wear factors decreases the amount of the operational potential of the object [4]. If the considered operating process is performed in Δt_u period of time where t_1 is a start time of a process and t_2 is it's end time then a change of the operational potential amount included in the object can be expressed according to the following formula:

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

where:
$Pu(t_1)$ - amount of operational potential for time t_1,
$Pu(t_2)$ - amount of operational potential for time t_2,
ΔPu - change of operational potential amount,
$c_z^i(\Delta t_u)$ - time function of wear factor no i dependent on object operation in time period Δt_u,
$c_{nz}^j(\Delta t_u)$ - time function of wear factor no i independent on object operation in time period Δt_u.

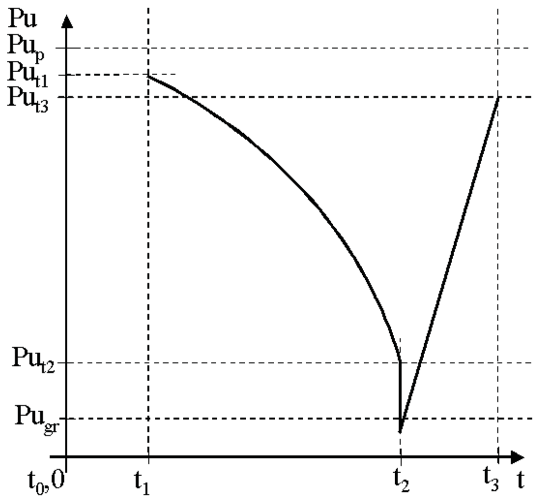

Fig. 1. The changes of operational potential amount during operating and service processes

During operating processes the amount of the operational potential is decreased. This can be expressed as a compound time function where inner functions are defined as a time functions of the wear factors.

During service processes, necessary exploitation properties are restored. The desired effect of service tasks execution is an ability state of a technical object [5]. The change of operation point of the object is connected with a change of an operational potential amount included in it.

The diagram (Fig. 1) presents the changes of the operational potential amount during operating and service processes. The operating process is performed in a time period $\langle t_1, t_2\rangle$. In the case of the analysed class of technical objects the service processes start immediately after the operating processes end, so they are performed in time period $\langle t_2, t_3\rangle$. The service processes can be realised as regeneration, replacement or modernisation [6]. On the diagram (Fig. 1) at t_2 moment of time a replacement of an element takes place. Because of that, at this moment the amount of operational potential violently decreases. Next, the operational potential is restored in a process of the element installation. It should be noticed that if the service process is realised by the replacement then the amount of operational potential included in the object at the moment of operation processes end (Pu_{t2}) is lost [7].

During exploitation phase the operating and service processes takes place on one technical object. They can be performed in the same time or in sequence. Therefore, in exploitation system there is an exploitation conflict between people who is responsible for object operation and object servicing [8]. This is a situational conflict [9]. The main reason of it is a dependence of operating and service activities and limitation of access to technical object. To solve the described problem the operating and service processes have to be managed together. Total maintenance management is very important not only because of exploitation conflict. It is also important because of increasing pressure concerning effectiveness of technical resources usage. So, total maintenance management is one of the most important steps to fulfil strategic goals of exploitation system [10]. Total maintenance application means that exploitation processes should be executed according to a developed and implemented maintenance strategy.

Analysing the time function of operational potential amount it can be stated that the strategy, which guaranties the highest quality of exploitation process, is the one, which minimizes the amount of the operational potential included in the object in the end of the operating process.

2. Characteristic of the object of the research

The carried on studies consider a hierarchical, complex exploitation system. This is the real system, which operates in purposeful way. In the system, controlled processes of machines exploitation are executed. The term “complex exploitation system” means a system, which can be divided into smaller subsystems and each of these subsystems can be considered as a complex system [11].

In a complex system we can distinguish a lot of different elements. The elements are connected and cooperate with each other. From the system point of view only these features of the elements are important which directly defines cooperation between elements and influence on a quality of the whole system operation [12].

The complexity of the system is determined by the number of the elements placed on different levels of system decomposition and a range of activities executed by the technical objects to fulfil defined goals of the system exploitation [13].

During the studies crucial systems are analysed. A failure of such systems causes economic and material loses or risk of such loses [14]. The considered systems are of strategic importance from the national economy point of view. It means that system operating process interruption should be coordinated in the range of a whole country. Additionally, the costs of a failure of the systems are much higher than a value of not generated effects of the system operation [15].

One of the most important attributes of a considered class of systems are costly and dangerous results of a system failure. The system failure can result in live and health hazard of site personnel, damage of the system elements or environment pollution [16].

The considered system is characterised by limited capability from diagnostic point of view where the diagnostic is understood as a process of object technical condition identification [17]. Due to constructional limitations of the exploitation system all three phases of the diagnostic process detection, localization and identification [18] can be performed only in a limited range.

Elements of the examined system are characterised by very high unitary costs. They belong to a group of exploitation materials, which according to V. Pareto model [19], make up very small in term of quantity (about 10%) and very big in term of value (about 70%) part of totality [20]. Therefore, time of storage of the elements for service process should be as short as possible.

The operating processes performed in the considered system are executed with high values of exploitation parameters. Therefore scheduled sequence of service processes should be obedient to the law regulations [21].

3. Analysis of usability of currently applied maintenance strategies

The most simple maintenance strategy of technical objects exploitation is an operation until a failure. If a regeneration process is cost-effective then the objects are repaired. Otherwise, the objects are eliminated or utilised in different way. An application of the described strategy doesn’t mean that technical objects aren’t serviced at all. Before the failure, the objects can be regulated and some exploitation materials can be replaced. The main benefits of the strategy implementation are a simplified maintenance management and a reduced service base. The main drawbacks of the strategy are costs of storage of spare parts and a risk of a failure appearance before the end of an expected time of exploitation [20]. The operation until failure makes use of maximum amount of an operational potential. Unfortunately, because of mentioned above disadvantages the strategy can be applied only in the case of the objects whose damage doesn’t become a disturbance of a natural environment or activities performed using these objects. Therefore, the strategy can’t be implemented in the case of analysed class of technical objects.

The maintenance strategy by service life consists in diversified services planning. The services create a service cycle. The basic assumptions of this strategy are a defined rage of service activities for each type of service, a periodicity of services realisation and a hierarchical structure of different types of services. Start dates and ranges of service works are constant, determined on the basis of legal documents, refined by an experience of a producer and informal corrections of service staff [22]. The service starts at a moment when the system reaches a critical legal status. This is the moment of time when the object used up its service life defined by a producer. At this moment the element should be replaced independently on its technical condition [23]. The service life can be expressed as a function of object operation time, object exploitation time, mileage, number of start-ups or production amount [20]. A technical condition of a machine for specified time t depends on the machine starting status for time t_0 and a course of wear factors in a time period $\Delta t = \langle t_0, t \rangle$. In the case of each specified machine the starting status and course of wear factors in the time period Δt has different values. Therefore, technical condition of each machine for time t is different. Thus, the biggest disadvantage of the described maintenance strategy is a service execution for the machines in different technical states. The range of the service activities is constant and determined by realisation comparable tasks by the machines. Because of that, it is not possible to make the most of an existing operational potential, applying the exploitation strategy by service life. The value of the service life of the machine is determined on the basis of exploitation analysis, research and experience. It is defined for mean conditions of the machine operation process. Therefore the service life can be expressed as a parameter, which is easy to measure but is only partially correlated with the amount of an operational potential enclosed in the exploitation system.

This is the result of the assumption that a multi-dimensional function of the operational potential consumption can be described using only one variable – a measure of the service life. In real exploitation systems, the operating processes conditions are different than mean values what modifies a rate of the operational potential consumption. Due to the fact, the rate of the operational potential consumption is not equal to the rate of the service life consumption.

The maintenance strategy by state consists in continuous control of technical state of machines to obtain diagnostic information. The information enables the supervisors of an exploitation process to make correct decisions about the exploitation system and its surroundings. According to this strategy, start time of service activities is not constant. The whole information necessary to identify a current technical status of an object and to predict its future statuses is obtained from diagnostic systems. The strategy by state is especially useful in case of a very intensive operation process where reliability should be very high because of high costs of a failure. The implementation of the strategy is justified only if the prediction of critical state appearance is made early enough to prevent disability of the object. The main disadvantages of the strategy are high costs of designing and creation the reliable diagnostic systems and high costs of computerised systems installation. Economic effects of the described strategy application highly depend on knowledge base. Very often it is necessary to employ big groups of scientists to control technical status on-line [24, 25].

According to the maintenance strategy by state the service process should start at a moment t_2 when critical state appears. Before service process execution, it is necessary to complete logistic processes, which consists in preparation of necessary resource of materials, energy and information on operating station. If the period of logistic processes execution is marked as Δt then a technical state of an object at a moment t_2 should be predicted at a moment t_2-Δt. In the case of complex technical systems, Δt period of time can be equal to several months [26]. Therefore, execution of exploitation processes according to the maintenance strategy by state requires a prediction of a technical status of the system for specified time t_2 several months in advance. At a start moment of an operation process the system includes operational potential $Pu_{t1.}$ According to maintenance strategy by state, at the moment t_2-Δt, on the basis of operation process course and current operation point, the start moment of service process t_2 is determined. The t_2 moment is defined by a prediction of technical critical state appearance, which is equivalent to Pu_{gr} operational potential amount enclosed in the system. It means that the course of an operating process in time period Δt is estimated. The process of operational potential consumption is described by a compound time function where inner functions are defined as a time functions of the wear factors (1). Future courses of wear factors are not known at t_2-Δt moment. Proceeding wear effects are only partially stable and learn and forecasting processes are probabilistic. Therefore, the technical status of a machine can change progressively in an undetermined manner [27]. What's more, assumed rate of an operational potential consumption can be different then an actual one. As a conclusion we can say that execution of exploitation processes according to the maintenance strategy by state doesn't facilitate precise determination of unutilized operational potential amount.

There are a lot of intermediate solutions between the maintenance strategy by state and the maintenance strategy by service life. These solutions consist in diagnostic systems installations in exploitation systems where exploitation processes are executed according to the maintenance strategy by service life. For all mixed strategies the operational potential consumption process can be described like in the case of the maintenance strategy by state and by service life. The mixed strategies comprise elements of the strategy by state and by service life. Therefore, implementation of them doesn't protect from failure or unutilized operational potential amount occurrence.

A different type of maintenance strategy is a strategy by efficiency. Implementation of the maintenance strategy by efficiency is related to increase in demand for modern and more efficient machines, what results in production of new types of machines in very short time intervals. Simultaneously, because of a very fast technical progress, new projects and constructions of machines include major changes of a conception what increases their efficiency. The efficiency of an object exploitation decreases below the value attainable by other object accessible on the market. In such a situation an analysis of the efficiency is performed. The result of the analysis helps to choose between exploitation of an old object and replacement using a new one. The analysis should consider only the period of time common for these two alternative objects [28]. This period begins when the new object exploitation starts and ends when the old object exploitation ends. The old object is characterised by exchangeable value at the start moment of the period, costs and effects of the exploitation in considered period of time and a value at the moment of utilisation. The new object is characterised by costs of creation, purchase, installation and start-up, costs and effects of the exploitation in considered period of time and an exchangeable value at the end moment of the period. If the replacement of objects is chosen then the exploitation process of the old object is stopped despite the fact that its operational potential isn't completely used up and costs of exploitation are lower then their critical value [29].

In the case of the maintenance strategy by efficiency again can appear a situation when at the end moment of the object exploitation there is the amount Pu_{t2} of the operational potential enclosed in the object and this amount is bigger than a critical amount Pu_{gr}. If the replaced object is destroyed then difference $Pu_{t2} - Pu_{gr}$ decreases the quality of the performed exploitation processes.

There is also maintenance strategy by reliability [30]. This strategy consists in making exploitation decisions on the basis of results of periodical monitoring of machines reliability. The machines are used until increased intensity of failures. This strategy can be applied only when results of failures don't violate regulations of work safety. Therefore, the maintenance strategy by reliability can't be applied in the case of crucial systems [14], which are the objects of carried on studies.

4. Characteristic of maintenance strategy by controlled consumption of operational potential

On the basis of the carried out analysis it can be stated that independently on a considered maintenance strategy, chosen from a set of maintenance strategies applicable in the case of critical objects, at a start moment of service processes there is amount of an operational potential enclosed in a system which hasn't been transformed into the effects of the system operation. In the case of the object replacement this amount is lost what decreases the quality of the exploitation system operation.

The minimization of the amount of the operational potential, which hasn't been transformed into the effects of the system operation, can be carried out thanks to the correction of the intensity of the operational potential consumption process.

In order to a rational execution of exploitation processes in a complex technical system it is necessary to implement a model of an operational potential consumption process. The model should provide the control of the dynamic of the operational potential consumption process. To do this, the model has to estimate operation point of the system for time t_2 on the basis of an identified operation point of the system for time t_2-Δt and a determined course of operational potential consumption process.

In the case of crucial systems the periodical servicing is mandatory. It is forced by law and controlled by a qualified staff [21, 31, 32]. Therefore, according to each described previously maintenance strategy the service processes begin at moment of time specified in advance. In such situation, there is an identified operation point of the system for time t_2-Δt and a determined time period Δt of operating processes execution (Fig. 2 – dashed-dotted line). The implementation of characterised model consists in control of dynamics of operational potential consumption process by controlling the intensity of operation processes. The main objective of the control is to transform all identified amount of operational potential $Pu_{t2\text{-}\Delta t}$ into the effect of the system operation in the determined period of time Δt avoiding technical object failure (Fig. 2 – solid line). Such way of exploitation processes execution will be named as maintenance strategy by controlled consumption of operational potential.

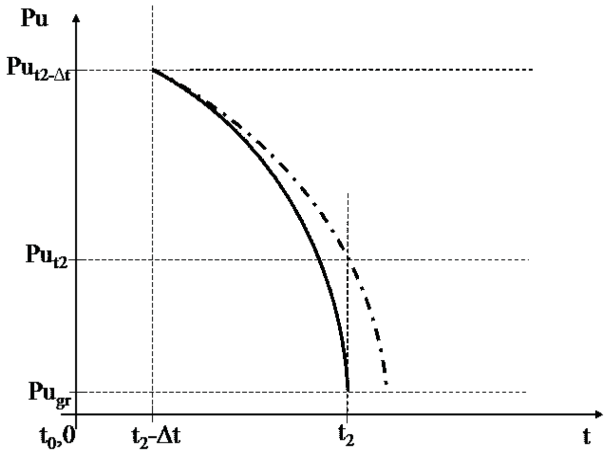

Fig. 2. The process of operational potential consumption – maintenance strategy by controlled consumption of operational potential

As it was already mentioned, the key issue of the maintenance strategy by controlled consumption of operational potential application is a creation of a model of concerned process. At this moment the universal model of an operational potential consumption hasn't been developed yet. Currently, the studies are conducted to create a mathematical model, which is an explication of the formula (1). The designed universal model will describe functional projection defining variation of operational potential amount enclosed in a technical object on the basis of time functions of wear factors.

5. Conclusions

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

- the consumption of the operational potential during operating processes can be expressed as a compound time function where inner functions are defined as a time functions of the wear factors,

- in the case of an object replacement the amount of an operational potential enclosed in it at the end moment of an operation process is lost,
- in order to perform rational exploitation of a technical object it is necessary to develop and apply an adequate maintenance strategy,
- the best maintenance strategy from the quality of executed exploitation processes point of view is the strategy, which minimize amount of an operational potential enclosed in a technical object at the end moment of an operation process,
- the operation until failure makes use of maximum amount of operational potential but the strategy can't be implemented in the case of analysed class of technical systems,
- in the case of maintenance strategy by service life the objects which are in different operation points are serviced with constant rage of service activities, therefore this strategy doesn't use up existing operational potential in optimal way,
- the realisation of exploitation processes according to the maintenance strategy by state doesn't facilitate accurate determination of unused operational potential amount because changes of a machine technical state can proceed progressively in undefined manner,
- in the case of the maintenance strategy by efficiency can appear a situation when at the end moment of an object exploitation there is the amount Pu_{t2} of operational potential enclosed in it which is bigger then critical amount Pu_{gr} what means that if the replaced object is destroyed then difference $Pu_{t2} – Pu_{gr}$ decreases the quality of performed exploitation processes,
- the maintenance strategy by reliability can be applied only when results of failures don't violate regulations of work safety so, it can't be applied in the case of crucial systems,
- 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 control of dynamics of an operational potential consumption process by controlling 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.

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