THE ANALYSIS OF MAINTENANCE MANAGEMENT STRATEGIES FROM THE OPERATIONAL POTENTIAL USAGE POINT OF VIEW

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Abstract

During the exploitation phase of the technical object a lot of different processes are curried out. All of them change the amount of operational potential included in the object. The most important processes from the operational potential point of view are the operational and service ones. The operational processes decrease and the service processes increase amount of the operational potential of the object. The amount of operational potential included in the machine is the most important factor of the machine operational condition. After operation period the object should be serviced to protect it against the failure. The length of the overhauling period is determined in different way according to the maintenance strategy executed in the exploitation system of the object. This is the main reason of different level of operational potential used in the operation process. In the paper different maintenance strategies are presented. The conditions of each strategy implementation were described. Each strategy were characterised from the technical object operational potential usage point of view. Additionally, main advantages and disadvantages of each strategy were explained. One the base of curried out analyses several difficulties of operational potential maximum usage were identified. The conclusions of the analysis presented in the paper are the base of the operational potential consumption model generation.

Keywords: *exploitation, maintenance management, operational potential*

ANALIZA STRATEGII REMONTOWYCH Z PUNKTU WIDZENIA WYKORZYSTANIA POTENCJAŁU UŻYTKOWEGO

Streszczenie

W fazie eksploatacji przebiegają procesy zmieniające ilość potencjału użytkowego zawartego w obiekcie technicznym. Podstawowe znaczenie dla zmian ilości potencjału użytkowego mają procesy użytkowe i zapewnienia zdatności. Procesy użytkowe zmniejszają, a procesy zapewnienia zdatności zwiększają ilość potencjału użytkowego w obiekcie. Ilość potencjału użytkowego determinuje przydatność maszyny do wypełniania stawianych jej zadań. Aby obiekt techniczny był w stanie zdatności należy po określonym okresie użytkowania wykonać jego obsługę. Moment przekazania obiektu z użytkowania do obsługi jest wyznaczany w różny sposób w zależności od strategii remontowej stosowanej w systemie eksploatacyjnym obiektu. Z tego powodu różny jest stopień wykorzystania potencjału użytkowego w poszczególnych strategiach eksploatacyjnych. W opracowaniu przedstawiono stosowane strategie eksploatacyjne. Zaprezentowano i mówiono uwarunkowania ich zastosowania w rzeczywistych systemach eksploatacyjnych. Każdą ze strategii scharakteryzowano z punktu widzenia wykorzystania potencjału użytkowego obiektu technicznego. Przedstawiono również możliwości i problemy związane ze stosowaniem poszczególnych strategii. Na podstawie przeprowadzonej analizy zidentyfikowano szereg trudności uniemożliwiających wykorzystanie istniejącego w obiekcie technicznym potencjału użytkowego w stopniu optymalnym. Wnioski wynikające z zaprezentowanej analizy stanowią podstawę do opracowania modelu ubytku potencjału użytkowego.

***Słowa kluczowe**: Eksploatacja, procesy zapewnienia zdatności, strategie remontowe, potencjał użytkowy*

1. Introduction

The exploitation is one of the phases of technical system existence in which the exploitation of the system operational resource take place [1]. Operational resource is inserted into the system during valuation, designing and producing phases. Technical system operation resource is called as an operational potential and interpreted as the system ability to working with specific efficiency. Simultaneously operational potential is unequivocally specified as technical position of the system.

At the beginning of exploitation phase system has an initial amount of operational potential. During the exploitation phase, processes that change the amount of operational potential of the system are carried out. The most important are the operational and service ones. The operational processes decrease and the service processes increase amount of the operational potential of the object.

Carried out operational processes transformed the system operational potential into the result of the system operation [2]. The result of technical system operation depends on efficiency of transformation process and the amount of operational potential consumed in operational process.

Operational processes decrease the amount of operational potential and at the same time they change the state of technical system from the initial state to the boundary one. Changes of the system state result from forcing factors influence. The forcing factors could be depended or independent on the system operation. At the moment when the system reached the boundary position it is necessary to start the technical system service process. This kind of strategy is called strategy by state.

In case of impossibility of the system state estimation the operational processes are carried out according to strategy by service life. The service life can be expressed by the time of object operation, the time of its exploitation, vehicle mileage, number of activations and production amount [3].

At the time when the services processes start there could be some operational potential amount included in the system. The amount of included operational potential depends on the applied exploitation processes strategy. If the renewal process is made by replacement then the amount of operational potential not transformed into result of system operation is lost.

The loss of unused operational potential decreases the efficiency of operational process and increases the system exploitation costs. That is why the minimization of unused operational potential is advisable. Unfortunately, the decreasing the amount of unused operational potential moves the system closer to its boundary state. When the limits of boundary state are exceeded the system could be damaged. So, in case of the systems, where losses caused by emergency devices interruption are bigger then value of operation effect by few to dozen times [4], there are two opposite criteria of renewal process start time determination.

Therefore, it is necessary to define the method of automatic optimization the length of overhauling period or control the dynamics of operational processes. Thanks to it, in a specific overhaul period it will be possible to convert the biggest amount of operational potential into the operation effect without exceeding the boundary state.

2. Exploitation strategy by state

Realization of exploitation processes in accordance to strategy by state requires determination of technical state of the system at t_z time. The state of technical object is determined by values of system attributes. System attributes are divided into two groups: measurable and non-measurable ones. In case of complex technical systems the determination of measurable attributes values require diagnostic system with very high installation costs level. Additionally, some of measurable attributes values could be determined only by destructive examinations so it is impossible to apply them in defined time t_z. Simultaneously, presence of non-measurable attributes makes accurate estimation of the technical state impossible.

In accordance to strategy by state, in a moment of boundary state t_z the realization of service processes is necessary. Before realization of service processes the logistic processes should be executed. These logistic processes should comprise the preparation of necessary materials, energy and information on the service stage [5]. If we call the period of time necessary for realization the logistic processes the Δt, then the system state for t_z time should be determined in a t_z-Δt time. In case of complex technical systems period necessary for logistic processes could be about few months [6]. Realization the exploitation processes in accordance to strategy by state require therefore the determination of system technical state for time with many months lead time.

Course of operational potential consumption process could be expressed as a function. Time is a domain of the function; the amounts of operational potential included in the technical system are the values (Fig. 1)

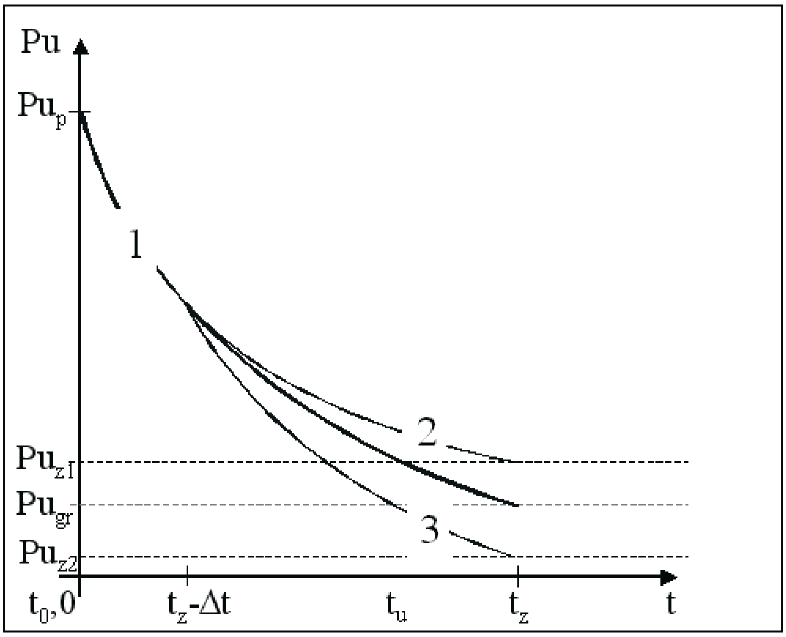

Fig. 1. Operational potential consumption process at time - strategy by state

In the technical system the Pu_p of operational potential is included at the beginning of the operation time t_0. At the t_z-Δt moment of time, based on operation process running and actual technical state, the t_z moment of service process start is determined. This moment is defined based on forecast of occurrence the boundary technical condition equals to Pu_{gr} - operational potential included in the exploitation system. It means, that indirectly the running of operational potential consumption process within the time Δt is forecasted (line number 1 on the Fig. 1). The process of operational potential consumption is a complex time function [7] directly dependent from time running of forcing factors (1).

$$P_{ugr} = P_u(t_z - \Delta t) + \Delta P_u\left(c_z^1(t)\Big|_{tt_z-\Delta t}^{t_z}, c_z^2(t)\Big|_{t_z-\Delta t}^{t_z}, \ldots, c_z^i(t)\Big|_{t_z-\Delta t}^{t_z}, c_{nz}^1(t)\Big|_{t_z-\Delta t}^{t_z}, c_{nz}^1(t)\Big|_{t_z-\Delta t}^{t_z}, \ldots, c_{nz}^j(t)\Big|_{t_z-\Delta t}^{t_z}\right), \quad (1)$$

where:

P_{ugr} - amount of operational potential for t_z moment,

$P_u(t_z$-$\Delta t)$ - amount of operational potential for t_z-Δt moment,

Pu - change of operational potential amount,

$c_z^i(t)\Big|_{t_z-\Delta t}^{t_z}$ - time course of i forcing factor dependent on operation of technical object within time interval: (t_z -Δt, t_z),

$c_{nz}^j(t)\Big|_{t_z-\Delta t}^{t_z}$ - time course of j forcing factor independent on operation of technical object, within time interval (t_z -Δt, t_z).

Assumed course of operational potential consumption process can differ from the real course because the future time courses of forcing factors are not known at the t_z-Δt moment and exact shape of ΔPu function is not known in many times [8].

If the consumption process is slower then assumed one (the second line on the Fig. 1) then at the t_z moment the amount of operational potential will reach the value Pu_{z1} bigger then $Pu_{gr.}$ The difference Pu_{z1} - Pu_{gr} is the amount of operational potential not transformed into the result of system operation that caused decreasing the quality of exploitation processes.

If the process of consumption will be faster then supposed one (the third line on the Fig. 1) then at the t_u moment, earlier then t_z the amount of operational potential will reach boundary value $Pu_{gr.}$ Further system operation cause failure and transition the object into the disable position. In case of technical systems, where the consequence of damage during the realization of exploitation tasks can be: loss of exploitation staff health or live, damage of systems elements or environmental pollution [9] such situation is unacceptable.

Technical and economic difficulties occurring during estimation of the technical object state and minimization of probability of disable position are the main reasons of strategy by service life application.

3. Exploitation strategy by service life

In case of realization the exploitation processes according the strategy by service life the service process starts at the moment when the system reach the legal boundary position. This is the moment when the established by manufacturer calendar service life or service life by work have been used up. After this moment the system should be serviced independently of its technical condition.

Service life could be determined as a variable with value correlated in some degree with amount of operational potential included in the exploitation system. The most important feature of service life is the susceptibility on measurement. The service life could be expressed by time of object operation, the time of object exploitation, vehicle mileage, number of activations and production amount. The value of service life is determined by manufacturer on the basis of exploitation researches and experiments. It refers therefore to the average conditions the device operates. In case of devices that could create health hazard and could be a menace to property and environment owing to under expansion of liquid or gasses being on the pressure different then atmospheric one, liberation of potential and kinetic energy during people or freight transportation in a limited range, propagation the dangerous materials during their storage or transport, the value of service life is determined by law regulations [10]. In this case the measure of service life is the exploitation time of the object.

Unfortunately the strategy by service life does not allow using the existing operational potential in an optimal way. This is the result of assumptions of strategy by service life, that multidimensional function of the operational potential consumption could be described by one variable accepted as service life measure. Additionally, the value of service life is determined for nominal conditions. In the real exploitation system the operational processes are carried out in different conditions. It changes the speed of operational potential consumption. That is why the speed of service life loss could not be linear dependent on the speed of operational potential consumption.

At the moment the operation process begins there is the initial amount of operational potential Pu_p included in the system. The exploitation system is characterized by the initial amount of service life R_p.

Realizing the operational processes according to the strategy by service life the t_z moment of starting the service process is determined on the basis of service life losses. This is the moment when the service life amount reaches the limited value equal to zero. This value is equivalent to the limited amount of operational potential Pu_{gr} included in the system.

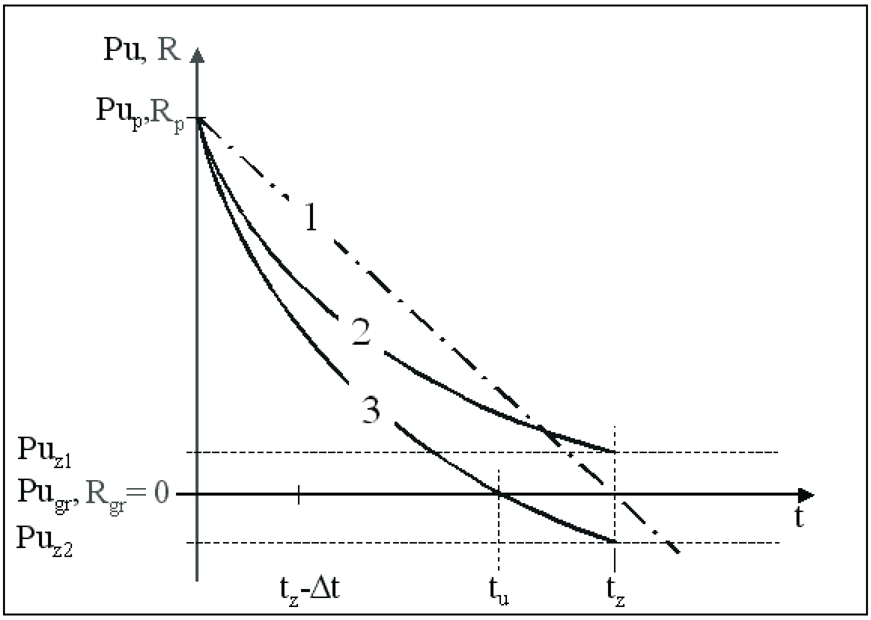

Fig. 2. The process of the operational potential consumption at time - strategy by service life

Process of operational potential consumption could run with different speed. If process of operational potential consumption runs quicker then process of service life loss (curve no 3 on the Fig. 2) then at the t_u moment earlier then t_z the object moves to disable position. If the process of operational potential consumption runs slower then process of service life loss (curve no 2 on the Fig. 2) then at the moment t_z when the service processes starts there will be the operational potential amount equals to Pu_{z1} included in the object. Similar to strategy by state the difference between Pu_{z1} and Pu_{gr} is the amount of operational potential not transformed into the result of system operation that caused decreasing the quality of exploitation processes.

4. Exploitation strategy by service life with system conditions consideration

As it was pointed out, during the industrial researches and studies carried out between 1999-2006, in case of complex technical systems the exploitation processes are not realized according to the strategy by state nor the strategy by service life [11, 12]. The strategy used is based on the strategy by service life, but the plan of overhauls is modified according the conditions resulted from bidirectional connections between the exploitation system and the external systems. Simultaneously, modification of the maintenance plan are made only in the direction of shortening the overhauling period that increases the amount of operational potential included in the system at the moment of beginning the service process. In relation to strategy by service life, the exploitation strategy really realized decreases the probability of failure at the costs of increasing the amount of operational potential not transformed into the effect of system operation.

This conclusion is confirmed by researches curried out in the area of domestic power engineering system. Value of the failure index for this kind of exploitation systems is calculated according the formula (2):

$$FOR = \frac{\sum_{i=1}^{n} t_{ai}}{\sum_{i=1}^{n} (t_{pi} + t_{ai})} 100\%. \tag{2}$$

where:

FOR - failure index,

t - power unit emergency down-time,

t_p - power unit working time

and is about 1.0% [13]. It means very low system failure frequency. Simultaneously, the amount of operational potential included in the system at the moment of starting the service process is very big.

As an example this value could by analyzed for complex exploitation system of thermal power station, which consists of 10 power units. In considered technical system exploitation processes are realized according the strategy by service life with systems conditions consideration.

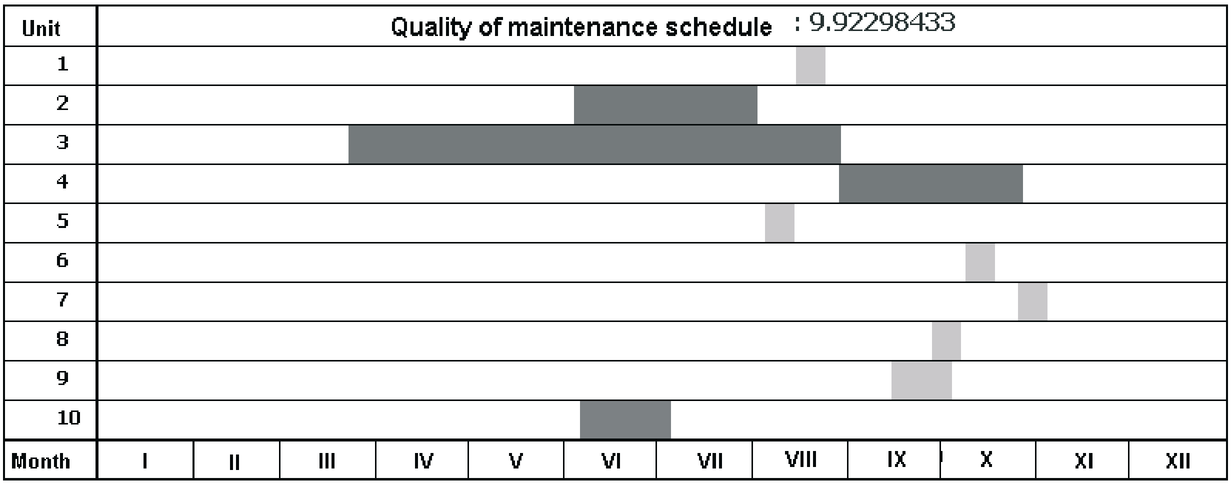

Fig. 3. Plan of the power unit overhauls - strategy by service life with systems conditions consideration

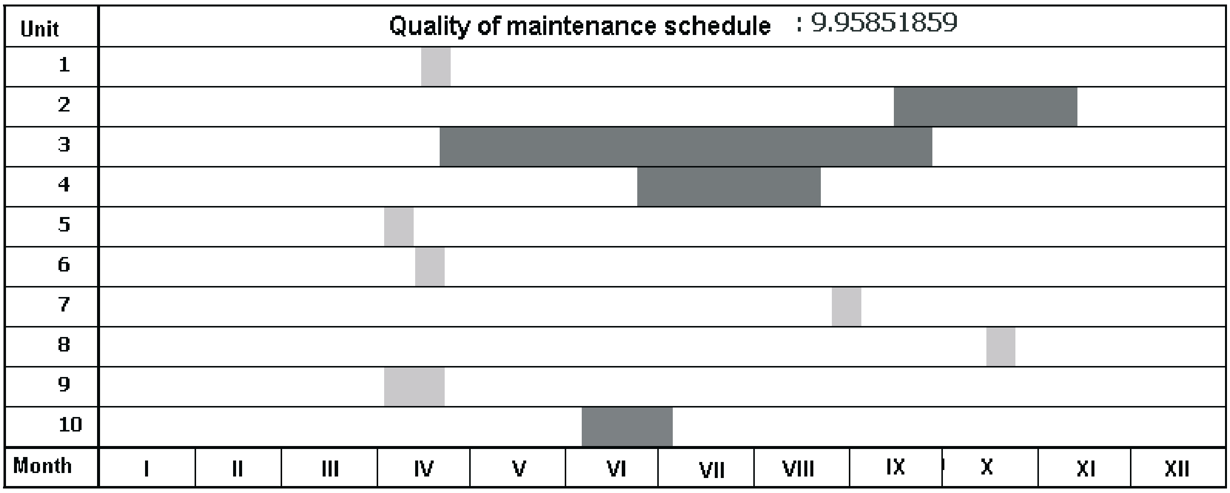

Fig. 4. Plan of the power unit overhauls - minimizing the amount of operational potential remaining in the object at the moment of starting the service process taking into consideration exploitation system conditions.

There are examples of power unit renewal graphic schedule on the pictures. Dark grey bar means general overhaul, light grey bars mean middle and average overhauls. Fig. 3 presents graphic schedule determined by approaching to meet the most all system conditions. In Fig. 4 we can see the graphic schedule determined with minimization the amount of operational potential remaining in the object at moment of beginning the service process taking into considerations all system conditions. The biggest difference between the moments of starting overhauls according both schedules could be observed for power units: number 2 and 3. In case of power unit number 2 the difference is equal to 100 days. If, for the preliminary estimation, we take the speed of operational potential consumption constant in time and the distance between services equals to 550 days, then the amount of operational potential for power unit no 2, at the beginning of service process is about 18% of its initial value. In case of renewing elements by changing we can noticed that about 1/5 of operational potential is lost.

5. Summary

On the basis of curried out analysis one can say that not depending on strategy of realization the exploitation processes at the moment of beginning service processes in the system exists some amount of operational potential not transformed into the result of system operation.

The minimization of amount of operational potential not transformed into the result of system operation could be done by changing the speed of operational potential consumption process.

To carry out the exploitation processes of complex technical system in an efficient way the model of operational potential consumption should be used. This model should allow the control on the dynamics of operational potential consumption. For that purpose model should allow to identify at the t_z-Δt moment the system technical condition for the t_z time. It should also allow the estimation of the operational potential consumption course in Δt period on the basis of knowledge the time - running forcing factors.

According to all exploitation strategies service processes start at the predetermined time. It caused the situation when we have the determined amount of operational potential for t_z-Δt time and period of currying out the operational process Δt. Characterized model application consists in control of operational potential consumption, thorough control the operational process to transform the most of operational potential into the result of system operation without damaging the technical object in specified period of time.

Presented approach implementation allows increasing the quality of the complex technical systems operation and decreasing their exploitation costs.

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