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A concept of application of the technical state change models of devices in ship operation process

INTRODUCTION

Planning of preventive maintenance operations of complex technical objects is aimed at optimization of their structure and regularity of their execution to assure a required level of operational reliability and performance quality of the object at a minimum labour consumption.

Current control of changes of object technical state is necessary for planning of preventive maintenance of devices. If technical diagnostics is applied to control rate of change of technical state of the objects it will be possible to determine their service life (time to limit state) and to appropriately plan their maintenance including repairs.

This end in view the models of change of technical state of objects, described in [3,7], i.e. :

⇨ deterministic one „**without history**" and
⇨ deterministic one „**with history**" can be used.

Their choice depends on an object's database being at disposal. Possible applications of the models to preventive maintenance planning of the objects on the basis of their current state in every operation phase are presented below.

CONDITIONS OF APPLICATION OF THE TECHNICAL STATE CHANGE MODELS OF DEVICES IN SHIP OPERATION PROCESS

It is assumed that the ship operation process can be devided into four main phases shown in Tab.1.

Tab. 1. *Assumed ship operation phases and planning of her technical maintenance*

Phases of ship operation	Planning system	Planning model	Aim of planning
Initial (~ 1 year)	planned- -guarantee	deterministic „without history"	guarantee assurance
Preliminary (up to ~ 4 years)	planned- -preventive	deterministic „without history"	optimization of preventive maintenance
Basic (up to ~ 20 years)	planned- -preventive	deterministic „with history"	optimization of preventive maintenance
Final (over 20 years)	supporting	deterministic „with history"	minimization of preventive maintenance

1st phase corresponds with the so-called guarantee period of ship operation, in which operations aimed at maintaining and recovering technical state are carried out in accordance with the planned-guarantee system. In this phase systematic information on technical use and reliability of ship's equipment is lacking. It is possible to obtain the information only on the basis of computational design data and reliability characteristics of devices available from producers, which can be deemed deterministic.Therefore in this operation phase the deterministic model „without history" can be applied.

2nd phase is the time of collecting and systematization of information on technical use and reliability of devices. Design data can be replaced by statistical data collected in service. They are not fully satisfactory ; therefore in most cases the task of optimum planning can be performed with the use of the deterministic model „without history"of ship technical state change.

3rd phase corresponds with the main – regarding its duration time – ship operation period. In this period a managing task is optimization of planning of intermediate technical maintenance of ships on the basis of detailed information on their technical usage and equipment state, with the application of the planned-preventive system. The 3rd phase should be preceded by systematic surveys and tests on ship equipment usage. This makes it possible to determine technical state changes of devices, occurred in the past. In the phase, application of the deterministic model „with history" is possible.

4th phase corresponds with the final period of ship operation when it goes on the system of supporting the technical state level and carrying out the so-called recovering repairs.

The most important – due to complexity of the equipment installed on ships, their profitability and operational safety – is the preventive maintenance strategy realized in accordance with wear records of the equipment. To elaborate such strategy it is necessary to accept an appropriate concept of prediction of operational time capacity of a given device with accounting for its operation conditions.

A CONCEPT OF PREDICTION OF DEVICE OPERATIONAL TIME CAPACITY WITH TAKING INTO ACCOUNT ITS OPERATION CONDITIONS

In the case of application of technical diagnostics with continuous monitoring of technical state of particular ship power plant devices it is possible to obtain a complete record of technical state changes of the objects since the beginning of their usage and to predict their operational time capacities at different operation conditions [8,9].

To illustrate the proposed prediction concept a simplified, linear change of the index ζ [7] which characterizes technical state of a device in function of time, is shown in Fig.1.

Below a method of estimation of the device operational time t_j for different operation conditions, on the basis of the proposed concept, is presented.

Changeable operation conditions of the technical objects make their wear rates changeable. Their loads and working media properties are random hence their changes can be described in the form of probability distributions. However gathering – from empirical investigations – appropriate sets of statistical information on wear rates of the devices in different operation conditions is very expensive and time-consuming.

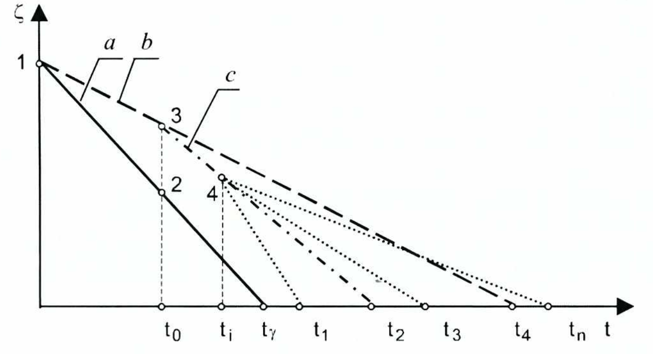

Fig.1. *Schematic diagram of technical state changes of a device in function of time :*

a *– technical state change within the gamma-percentage capacity of operational time t_γ*
b *– technical state change in new operation conditions till the time t_o of updating the device's state from state 2 to state 3*
c *– technical state change after its actualization*
2-3 – representation of the device's state actualization
4 – beginning of predicted state changes for different operation conditions
$t_j \in t$ (j=1,2,...,n) – correct operation times of the device (operational time capacities) at different operation conditions

Therefore it would be reasonable to make use of possible prediction of the wear rate distributions and – on their basis – of operational time capacities of the devices.

A way of assigning the capacities to statistical operation conditions of the device is presented on the following simplifying assumptions :

- wear values at initial and new operation conditions are the same
- wear rate distributions are the same at identical physical influences on the device
- change of operation conditions of the device (in the sense of their deterioration) causes a horizontal shift of its wear rate distribution towards greater wear rate values, however the form of the distribution remains unchanged (Fig.2).

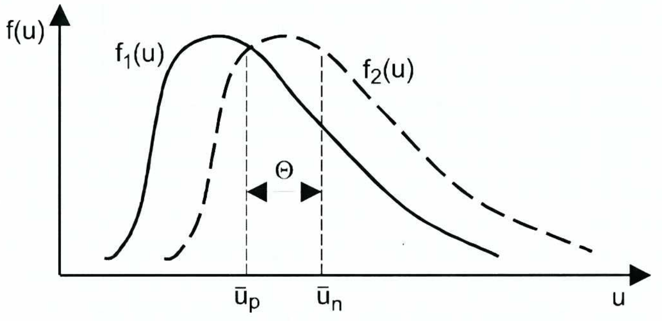

Fig.2. *Schematic diagram of wear rate change of the device due to change of its operation conditions :*
$f_1(u)$ – distribution at initial conditions
$f_2(u)$ – distribution at new conditions
Θ – shift of distribution

Difference of the expected values of the device wear rates at two different operation conditions is equal to the horizontal shift of the distribution, Θ, expressed as follows :

$$\Theta = \bar{u}_n - \bar{u}_p = \bar{u}_p(k-1)$$

where :

$$k = \frac{\bar{u}_n}{\bar{u}_p}$$

$\bar{u}_n, \bar{u}_p$ – mean expected wear rate values at new and initial operation conditions of the device, respectively.

On the above mentioned assumptions the relative change of operational time capacity, t_n/t, of an arbitrary device can be expressed as follows :

$$\frac{t_n}{t} = \frac{\dfrac{u_p}{\bar{u}_p}}{\dfrac{u_p}{\bar{u}_p} + k - 1}$$

where :

$u_p = \frac{z}{t}$ – calculated wear rate at initial operation conditions

z – wear value of the device during time *t*.

In order to determine the relative change of operational time capacity the following data would be necessary :

- information on changes of device's operation conditions
- estimation of influence of these changes on wear rate of the elements
- information on statistical values of the ratio of the calculated and mean wear rates of the elements.

Current technical state control and the determined operational time capacities of the devices can be used as the basis for planning their preventive maintenance.

PLANNING OF INTERMEDIATE PREVENTIVE MAINTENANCE OPERATIONS WITH THE USE OF THE DETERMINISTIC MODEL „WITHOUT HISTORY"

Planning of intermediate preventive maintenance operations with the use of the deterministic model „without history" can be carried out on the basis of the statistical or design data of the power plant, its technical usage and reliability of particular devices.

Analyses of statistical data on equipment failure-free operation and durability as well as technical documentation can be a source of information on equipment reliability.

The statistical data on elements of power plant equipment should inlcude a.o. the following information : average voyage duration, average operation time of a device during voyage, load distribution of a device during voyage, characteristics of used working media.

A result of planning of the maintenance operations should be their structure and range. And, an aim of optimization actions is planning of such sequence of their realization as to satisfy operation effectiveness criteria of the device [8].

A system of preventive maintenance planning of power plant objects, whose schematic diagram is shown in Fig.3, can be useful to realize the above mentioned aims.

The above outlined planning system can be useful at the beginning of operation process. In the next operation phases, when a database on an exploited device already exists, maintenance planning can be realized by using the deterministic model „with history".

PLANNING OF INTERMEDIATE PREVENTIVE MAINTENANCE OPERATIONS WITH THE USE OF THE DETERMINISTIC MODEL „WITH HISTORY"

A more perfect system of preventive maintenance planning can be achieved by passing from the planning based on statistical data to that based on information on current technical state of the devices and on ways of their operation.

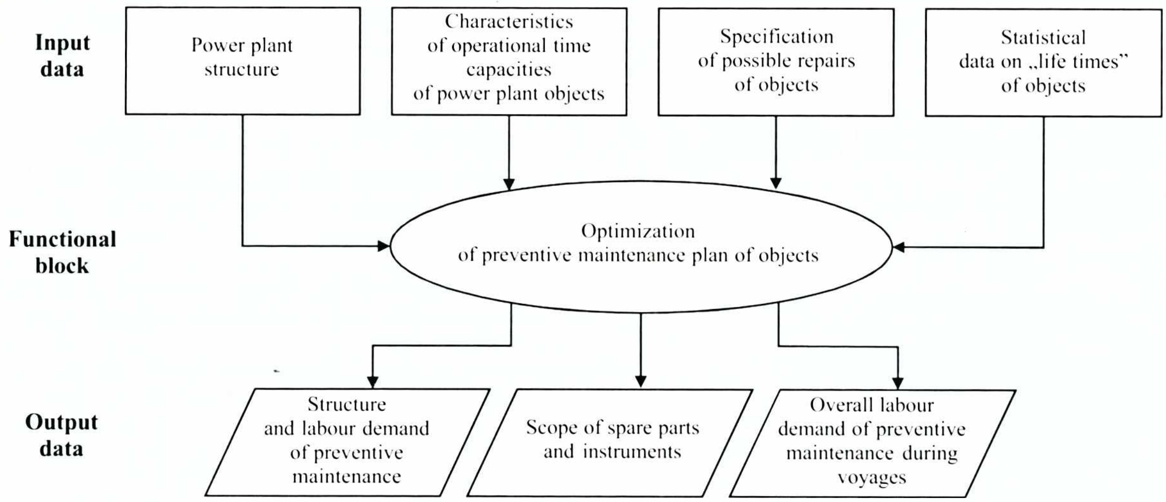

Fig.3. Schematic diagram of a preventive maintenance planning system of power plant objects at the beginning of operation process

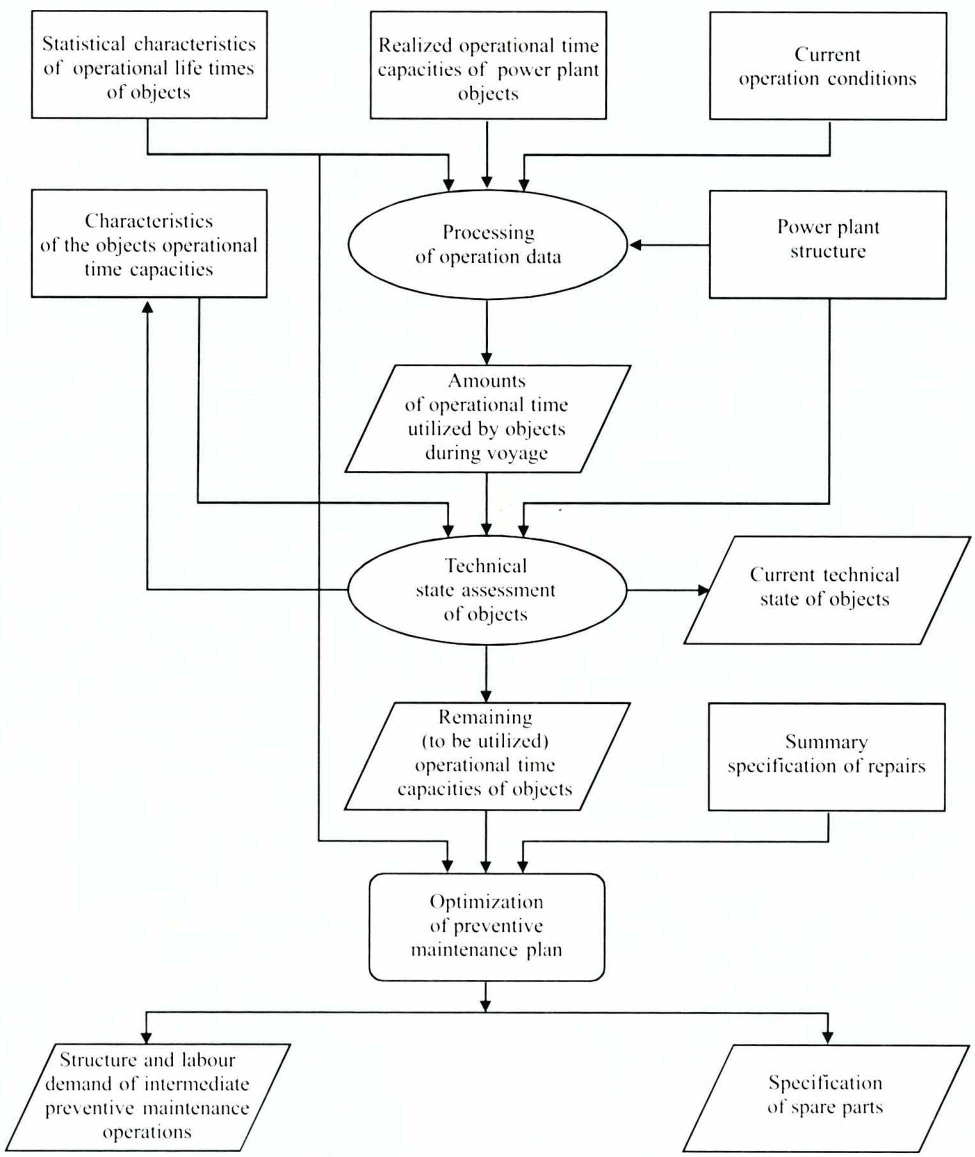

Fig.4. Schematic diagram of a preventive maintenance planning system of power plant objects with the use of the deterministic model „with history"

This way a resilient planning system of preventive maintenance could be introduced making reduction of range of maintenance operations possible [1,6,8]. „History" of technical objects can be determined on the basis of systematic overhauls or by applying technical diagnostics.

A schematic diagram of a more complex system which could be useful in preventive maintenance planning is shown in Fig.4.

The maintenance planning systems outlined in Fig.3 and 4 can be used for realization of optimization tasks for which appropriate criteria of operation effectiveness of the technical object should be applied.

SHIP OPERATION EFFECTIVENESS CRITERIA

In general, the profit Z_E obtained from operation can be deemed a criterion of ship operation effectiveness, which can be expressed as follows :

$$Z_E = k_{SU} \cdot t \cdot \overline{D} - K \rightarrow \max$$

where :

Z_E – profit obtained from operation of a ship

K – ship operation cost

$$k_{SU} = \frac{t_{SU}}{t} = \frac{t_{SU}}{t_{SU} + t_{TM}}$$

t_{SU} – summary operational time of ship usage

t_{TM} – summary time of technical maintenance including preventive operations

$\overline{D}$ – average profit per unit of ship operation time t.

For a given ship operation time t, average unit profit $\overline{D}$, and constant operation cost K, the maximum profit criterion is reduced to the following condition :

$$k_{SU} \rightarrow \max$$

It means that during ship operation minimization of the technical maintenance time t_{TM} should be aimed at, thus the summary ship operational time t_{SU} would be maximized.

This can be obtained by lowering the number of preventive maintenance operations and/or range of work to be realized within the operations.

The shipowner's cost K incurred during ship operation is the sum of the following elements :

$$K = K_P + K_F + K_{TM} + K_{OC}$$

where :

K_P – personnel costs (crew wages)

K_F – cost of fuel and lubricating oil etc

K_{TM} – cost of preventive technical maintenance and that resulting from failures

K_{OC} – other costs.

With the exception of the cost K_{TM} the remaining elements are approximately constant for a given ship. It means that the cost of shipowners can be minimized by decreasing the cost of technical maintenance operations, especially preventive ones.

Hence the second criterion for profit maximization, together with the above mentioned, is the following :

$$K_{TM} \rightarrow \min$$

In normal operation conditions the greatest component of the costs is the personnel cost (about 40÷48%) and the fuel/lubricating oil cost (about 40÷46% of overall cost).

The technical maintenance cost amounts only to about 5÷8% of the overall cost, with growing tendency at the end of ship's life. Therefore lowering of that cost does not lead to important advantages. Therefore applying both the above mentioned criteria together seems most profitable i.e. :

$$k_{SU} \rightarrow \max \quad \text{and} \quad K_{TM} \rightarrow \min$$

However it should be taken into account that the criteria could be rationally applied, especially in the case of preventive maintenance, under two following conditions :

- when the considered devices have monotonically increasing risk functions because only then carrying out preventive maintenance is justified
- when the cost resulting from failures (direct and indirect) are greater than the cost of preventive maintenance operations.

FINAL REMARKS

- The presented concept of predicting operational time capacities – after its development and practical testing – would be helpful in preliminary planning of preventive maintenance of devices and selecting an optimum plan of its realization.
- In the proposed concept only technical aspect was considered. Taking into account of the described economical criteria is a seperate problem.
- Further research aimed at development and practical implementation of the concept is under way.

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