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THE MAINTENANCE OF THE SHIP TURBINES WITH THE APPLICATION OF THE KEY PERFORMANCE INDICATORS

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Abstract

The article presents the aspects of the application of the maintenance key performance indicators (KPI) in the management of the operation of the ship turbines on the floating vessels. There have been indicated the significant measurable technical, organisational and economic features of the management systems which determine the decisions related with the turbine maintenance in the good usability condition pursuant to the intended criteria. The indicators selection methods have been classified and reviewed. There has been made an attempt of the interpretation of some of their selected values. The reference has been made to the application of the indicators in the Computerised Maintenance Management Systems (CMMS) and the application of these systems in the control processes for the ships' power systems.

Key words: *Performance indicator, gas turbine, steam turbine, KPI, power system, floating vessel*

1. Introduction

The operation of the power systems of the floating vessels is nowadays a process subject to more and more specific monitoring. The contemporary supervision, measurement, recording and data acquisition/archiving systems, the faster and miniaturised computers and the universal and open software offer the appropriate conditions for that purpose. The data acquired become a valuable information resource, and their identification and analysis allows to rationalise the control of the operation process and improve the performance of the power systems [1].

The maintenance of the power systems on the floating vessels refers to the diversified activities aiming to maintain the functional usability of machinery, equipment and installations. The maintenance is a concept frequently encountered in the technical literature related to the operation theory and practice [1, 2, 3, 4, 5, 6, 7, 8, 9]. At times the concepts like operation maintenance or maintenance in operation are used as well. All these issues mostly refer to the behaviour of the technical objects in the usable condition and readiness for use at the expected level and in due time. The maintenance comprises the activities both directly related with the technical object and the supporting activities, usually related with the object of operation indirectly through the activities within the management, information, logistics etc. The maintenance consists of the following activities [2, 3, 6]:

- technical service (repairs, overhauls, adjustments etc),
- logistic services/logistics of the spare parts and usable media,
- information acquisition on the objects of maintenance,
- the management of the knowledge and technical personnel,
- establishment and implementation of the periodical service procedures,
- diagnostics for the operation needs.

Maintenance is, next to the using, a key operation element, which in terms of the presently emphasised needs of the ships and other watercraft owners, requires precise monitoring for the purpose of the planning and the execution of the individual tasks in the satisfactorily efficient manner. The efficiency or in other words performance can be understood in different ways depending on the branch and conditions applicable for its evaluation. In the operation systems this is a property to satisfy the requirements in various terms: of reliability, economic, quality, capacity, power etc. [5]. The essence of the performance evaluation is the determination of the probability to maintain by the system of the nominal outputs during the use [4]. The performance of the operation systems is thus determined in the categories of the results achieved or expected [6] combining the applicable information groups from the selected areas of the operation and maintenance of the technical objects.

The lifecycle of the technical objects is divided into four stages which chronologically are as follows:

- stage I – the determination of the needs and designing,
- stage II – preparation for the operation, transportation, assembly, commissioning,
- stage III – the operation,
- stage IV – utilisation (post-operation use).

For the marine power plants at the stage of the ship design (I) there are determined the factors related with the implementation of the basic and auxiliary functions of the technical objects in the power systems:

- related to the mass and overall dimensions (unit mass and unit overall dimensions of the engines, machinery, equipment, installations and the entire engine rooms – of particular usability at the design stage,
- related to the technological aspects,
- related to the standardisation conditions,
- related to the unification qualities,
- related to the ergonomical features,
- related to the permissible vibration level in the engine room,
- related to the noise level,
- related to the microclimate conditions, i. e. temperature, relative humidity and air pollution.

At the stage of the implementation and operation (stages II and III) the need of information acquisition is manifested to enable the description of both the use and the maintenance of the individual elements of the power systems. Pursuant to the conducted measurements of the operation properties of the machinery and the equipment installed on watercraft, organisational and economical conditions, there are determined the significant information groups which are to be representative of the results, quality, capacity, and profitability of the operation activities which are carried out. Their presentation is done by use of the key performance indicators (KPI) which presently form one of the basic tools of the rational operation management of the technical objects [7].

For the complex and varied technical systems such as marine power plants the performance indicators must be strictly defined and explicitly interpreted [13].

2. The Purpose of the Application of the Ship Turbine Maintenance Key Performance Indicators

The ship propulsion turbines, regardless whether their effective power is generated by means of steam (steam turbines) or combustion chamber exhaust gases (gas turbine), constitute an essential element of many systems of marine power plants. Despite the high reliability of ship turbines their performance in the main propulsion systems and the auxiliary power set-ups (eg production) is subject to more and more intensive monitoring. Additionally, nowadays, the contemporary conditioning in all micro-economical systems demand more precise cost control and optimisation of the operation systems aiming at the reduction of the expenses for the maintenance with the simultaneously kept reliability at the expected level.

The performance of the maintenance of the marine turbine power systems on floating vessels is a significant issue in terms of rationalisation of many aspects of human activities involving the use of marine transport, capacity and production units, marine oil rigs, FPSO and navy units [1, 2, 3].

The key performance indicators of the marine turbine maintenance describe the selected information groups in order to present the outputs of the examined power systems in the up-to-the-point manner and in the explicit way. The purpose of the application of the key performance indicators of the maintenance is:

- the obtainment of the current and historical values of the measures of the operation properties and their mutual relation, in order to compare the achieved values with the design values as well as with the values obtained in the course of observation of other operation systems and other technical objects,
- the diagnostics of the implemented maintenance activities,
- the implementation of the process of the continuous improvement through the search and elimination of any meaningful deviations from the assumed design figures,
- the monitoring of the changes and progress in the operation system,
- the motivating and accounting the technical and management personnel for the effects achieved.

The performance indicators discussed in this article refer to the examination and analysis of the power systems in terms of providing the desired information chiefly for the higher and middle management levels in charge of the proper maintenance in the technical, economical and organisational sense. However, there is an information group remaining so far beyond the analyses related with the key performance indicators, and at the same time significantly influencing the economical aspects. These are related with the power performance and their combination with the other indicators and the analysis of their effect on the operation management is the subject of the research conducted by the authors of this article [4, 5, 6, 13].

3. The Applied Maintenance Performance Indicators

The maintenance performance of the power systems of the floating vessels most frequently refers to:

- the quality of the implemented maintenance processes,
- the quality of the functioning of the machinery, equipment and installations,

- the organisation and effectiveness of the work of the technical personnel and
- costs and profitability of the maintenance activities implemented.

The key performance indicators of the maintenance have been formed in three categories [6]:

- economical indicators,
- technical indicators,
- organisational indicators.

In each group there have been separated the indicators on the general, intermediate and specific levels [6, 8]. Using the symbols applied in [6, 8, 9] the division of the indicators pre-defined in these materials is shown in the table 1.

Table 1. The structuring of the machinery maintenance performance indicators [6, 8, 9]

	Economical indicators	Technical indicators	Organisational indicators
Level 1 – general/owner's (e.g. watercraft set)	E1, E2, E3, E4, E5, E6	T1, T2, T3, T4	O1, O2, O3, O4, O5, O6, O7, O8
Level 2 – intermediate (e.g. floating vessel power system)	E7, E8, E9, E10, E11, E12, E13, E14	T5, T6, T7, T8, T9, T10, T11, T12, T13, T14, T15, T16	O9, O10
Level 3 – specific (e.g. gas turbine)	E15, E16, E17, E18, E19, E20, E21, E22, E23, E24	T17, T18, T19, T20, T21	O11, O12, O13, O14, O15, O16, O17, O18, O19, O20, 021, O22, O23, O24, O25, O26

In the standards [8] there have been included the indicators recognised by the Technical Committee CEN/TC 319 "Maintenance" as the essential ones. However, this does not mean that the companies and institutions dealing with the operation of floating vessels [or watercraft in general] have any restrictions imposed upon. KPI are established and selected on the basis of the individual information needs in every operation system. Below there are presented the selected predefined in [8] and [6] key performance indicators of the maintenance of the turbine ship power plants with steam turbines and gas turbine engines.

Amongst the technical indicators one of the most often applied KPI is the availability A of a specified machine or the entire power system. This value corresponds to the readiness K used in Poland. There are distinguished technical availability A_T and the operational availability A_o.

$$[T1]\ A_t = T_{OT} / (T_{OT} + T_{DT.M}) \quad (1)$$

$$[T2]\ A_o = T_{UT.t} / t \quad (2)$$

where:

T_{OT} – total operation time

$T_{DT.M}$ – summarised downtime caused by maintenance activities

$T_{UT.t}$ – usability time in calendar time t

The indicators T1 and T2 allow to specify the reliability of the individual objects or the entire power system. Other technical indicator used to specify reliability is the mean time between failures (MTBF).

$$[T17]\ MTBF = T_{OT} / F \quad (3)$$

where:

F – number of failures

KPI applicable not only for the performance of the maintenance, but also object response to renewal/repair is the mean time to repair (MTTR).

$$[T21]\ MTTR = T_{DT.M} / F \tag{4}$$

One of the most frequently applied organisational indicator on floating vessels is the ratio of the planned tasks to the whole value of available manhours.

$$[O5]\ O_W = WO / WF \tag{5}$$

where:
WO –the planned sum of manhours of maintenance activities
WF –the available sum of manhours of operation maintenance activities

From the economical pint of view the profitability indicator is often applied related to the costs of maintenance in the event of object or system replacement.

$$[E1]\ E_I = C_M / C_{Re} \tag{6}$$

where:
C_M *– total maintenance cost*
C_{Re} *– total replacement cost*

Or the maintenance cost indicator in relation to the operation or capacity parameter (e.g. in case of FPSO unit to one tonne of the oil product).

$$[E5]\ C_P = C_M / P \tag{7}$$

where:
P *– production capacity*

Also the performance of the warehousing/storage management is measured. An example of an indicator in this respect may be also the ratio of the total costs of the operation means/spare parts used in the activities of the maintenance of the stores value in a given period of time t.

$$[E12]\ E_{WT} = C_{Materials.t} / V_{Materials.t} \tag{8}$$

where:
$C_{Materials.t}$ – *the total cost of materials used for maintenance in operation during the period of time t*
$V_{Materials.t}$ – the average value of the materials stored to be used for maintenance in operation during the period of time t

4. The Maintenance Performance Indicators Selection Methods

The selection of the key performance indicators of the maintenance is most frequently done by use of the expert's method. It consists in the selection of the indicators from the entire operation range. This method takes its origin in the practices of project management and it is possible to use, if the following conditions are met:

- there is available personnel/workers who being aware of the functionality of the individual KPI are capable to decide in the general discussion which indicators in the specific part of the system operation would be applicable,
- in the group working over the selection there are persons from the different organisational levels (technical workers, lower management, upper management),
- if the performance indicators are used in parallel in the other parts of an enterprise (e.g. in relation to the floating vessels), then the definitions of the

individual components are made uniform and are known to the group of the experts working on the selection of the indicators for the power systems operation.

The experts' method is largely employed in the management of the operation of the floating vessels. The selection of the performance indicators by use of this method is strongly subject to the experience and knowledge of the specialist team members.

5. The Examples of the Key Performance Indicator Values in Turbine Maintenance

The adequately selected and presented KPI are likely to contain high information value. Owing to the proper interpretation the rational and reasonable operation decisions can be made, amongst others related with the repair planning, organisational changes, planning of purchase and spare parts deliveries etc.

By use of the Monte Carlo method the simulation examinations have been conducted for 30 ship turbines. The simulation of the mean time between critical failures [MTBFc] has been conducted by the application of the value sampling from the normal distribution under the assumption that the mean value of failure intensity $\lambda_{śr} = 605.9$ is the same as the value quoted by OREDA-97 manual [12] for the selected group of turbine engines. For the demonstration of the deviations it has been assumed that the standard deviation is S = 200. The figure 1 presents the obtained MTBFc values. The graph has also marked median M and the values: median +20% - $M_{+20\%}$ and median –20% - $M_{-20\%}$. It has been assumed that that the value $M_{-20\%}$ is the minimum expected value for this engine generation. Thus the range has been determined which for the examined generation group is recognised as the normal value range (values $M_{-20\%}$ and bigger).

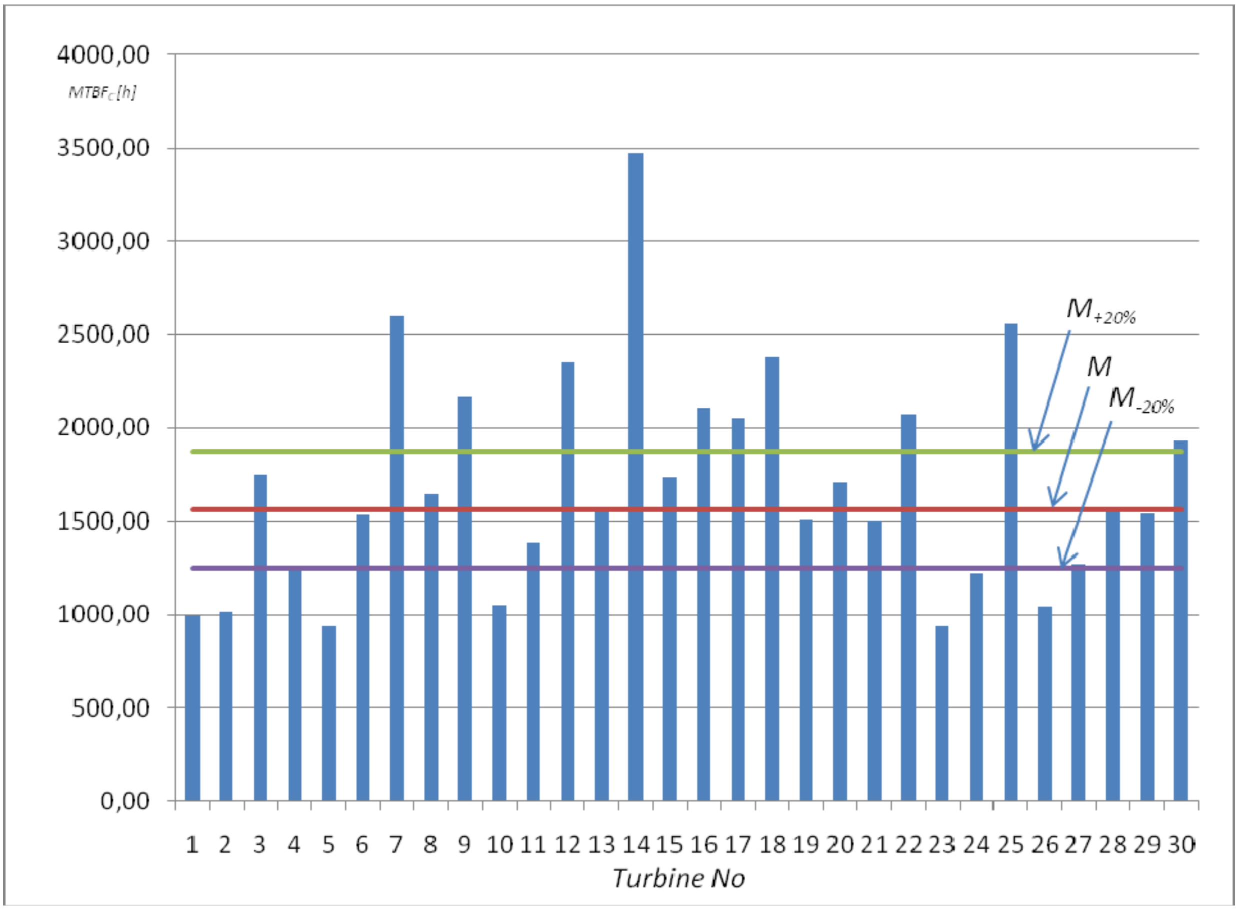

Fig 1. The values of the $MTBF_c$ indicator for the generation of 30 marine turbine engines

On the basis of the analysis of the simulation results there has been obtained the set of the turbine engines below the expected (normal) values. So presented data may also be interpreted by the statement that the performance of maintenance (in terms of reliability) of turbines marked as 1, 2, 5, 10, 23, 24, 26 is unsatisfactory (below the expected values). However, analysis of only MTBF indicator is not sufficient to make significant organisational or technical decisions.

The figure 2 shows the obtained values of $MTBF_c$ together with the values of the mean time to repair of the critical failures $MTTR_c$ obtained by the application of similar simulation and the total annual maintenance costs in relation to the unit of generated power C_p.

The starting values for the MTTR simulation have been taken, similar as for MTBF, from the manual OREDA-97 [12], whereas the economical values have been taken from the data made available by the Northeast CHM Application Centre of the University of Massachusetts (USA). On the basis of the obtained values of the mean time between failures, mean time of repair $MTTR_c$ and the annual maintenance costs in relation to the unit of the power generated C_p as presented in the figure, the preliminary evaluation of the maintenance performance has been done. Engines marked with 2, 5, 10 and 24 whose mean time between failures amounts to less than the minimum expected value $M_{-20\%}$ and at the same time the mean time for critical failure repair and the total annual maintenance cost are relatively high. These engines are maintained much less effectively than the remaining ones from the examined generation.

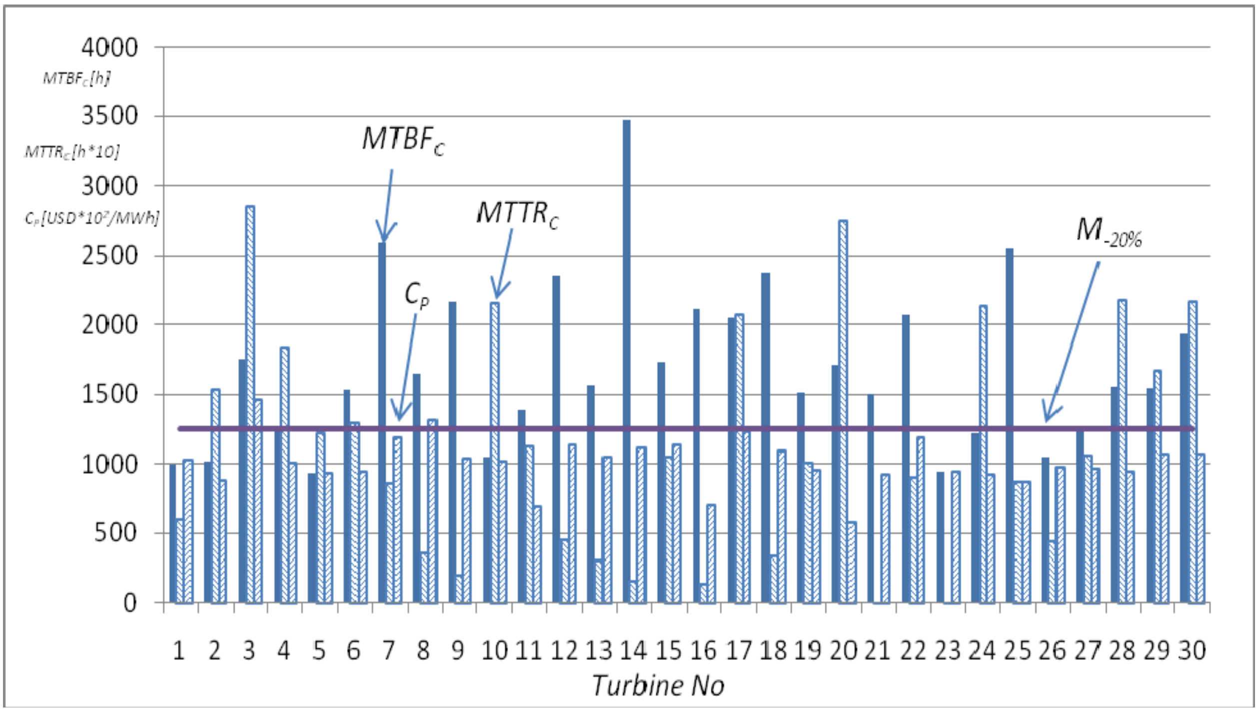

Fig 2. The values of the $MTBF_c$, $MTTR_c$ and C_p for the generation of 30 marine turbine engines

The improvement in the performance requires the implementation of specified organisational and operational activities, as well as some construction changes may be justified. The examples of the activities to improve the performance of the identified turbines could be:

- service procedure review and modernising,
- training for the crew operating/servicing the turbines,
- the implementation of additional procedures within the spare parts management,
- planning of general overhaul in the power systems where these turbines are installed,

- the implementation of extraordinary control procedures (inspections, diagnostics for the maintenance needs).

The selection of the activities to be taken aiming to improve the maintenance performance of the power systems depends on the components specified by the other indicators of this system and on the investment possibilities of the company or institution in charge of the operation. The rationalisation of the activities within maintenance is usually conducted on the basis of the leading criterion which may be for instance reliability or the total maintenance cost. It is of particular importance to establish the desired and alarm values of the individual indicators for the whole system as well as for its individual elements. The majority of the CMMS [Computerised Maintenance Management System] systems offered on the market makes possible the automation of the KPI value control. The notification of the alarm value being exceeded may be done by the message in the system, but also by e-mail to a person appointed to be in charge of the specific part of the power system. Automation of the notification process is usually related with the inclusion of the ship owner's office of a floating vessel into the group of alarm messages recipients.

6. Summary

The key performance indicators of the ship turbine maintenance formulated in the article are the appropriate set of values credibly evaluating the assessment and the correctness of the operational decisions made within maintenance. This thesis is applicable to the engines in ship's power systems in the technical scale as well as for obtainment of the information for the construction of the prediction models for the needs of the ship owner's logistics. The sources of the information presented by means of the key performance indicators may be historical data concerning the frequency and nature of the operational events as well as the data obtained by way of simulation examination adequate to the investigated maintenance process of the technical objects.

The research begun by the authors of this article within the evaluation of the applicability of the discussed key performance indicators consists the introduction to the further examinations of the construction of the model of maintenance evaluation of ship's power plants and other power systems. It is supposed to use not only the aforementioned information, but also other data, so far never analysed in connection with the key performance indicators.

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