The method of diagnosing objects of the ship power plant of inland navigation vessels

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Abstract. The main provisions of the method for determining the technical state of the ship's power plant for inland navigation vessels, based on the use of system analysis, in accordance with which the objects of the power plant are conditionally ranked, are described in this article. The indicators of their technical state, determined by the testimony of numerous sensors, installed on these objects, are appropriately transformed into partial criteria of the technical state, and systemic synthesis, allowing numerous technical state criteria to be used to determine the integral indices of the technical state. The method is to be applied in automated systems for diagnosing power plants and their objects.

1. Introduction

While creating automated systems for diagnosing the technical condition of a ship's power plant (SPP), any of its objects can be considered as a technical system that represents an ordered set of a certain number of jointly operating elements (units, components, parts) and is designed to perform specified functions [1, 2].

Each technical system is characterized by a well-defined structure and mode of operation [3]. Under the structure of the system [4] we usually mean the nature of the relationship and interaction between the elements of the system, determined by the system’s geometric dimensions, mechanical, thermal, electrical and other parameters. The numerical values of $X_1$, $X_2$, ..., $X_n$ sufficiently fully characterize the technical condition, performance and quality of operation of any technical means or mechanism at a given time. During operation, the parameters of the technical condition vary from the passport values to the limit (from $X_{P1}$, $X_{P2}$, ..., $X_{Pn}$ to $X_{L1}$, $X_{L2}$, ..., $X_{Ln}$), which are usually justified by the technical and economic feasibility of further operation of the object. The difference between the current and passport values of the parameters $\Delta X_i = X_{Pi} - X_{Li}$ characterizes the degree of deviation of the parameters of the object technical condition from the standard. The technical condition and performance of complex objects, such as an internal combustion engine (ICE), is characterized by a set of parameters [5]. Further, under the technical condition of any object of the ship power plant (SPP) we will understand the level of its efficiency, serviceability and compliance with the requirements established by the regulatory and technical documentation.

2. Method review

The technical condition $TC_i(t)$ of each object of SPP at some operating time $t$ is the function with the following parameters:

- initial technical condition due to the design features, quality of materials and production of the object $X_{Pi}$;
• operating conditions characterized by parameters \( Z_i \);

• patterns of changes in the technical condition \( F_i \), which is formed depending on the nature of the processes of wear and destruction of the main parts, components and depends on the complexity of the design, operating conditions, assembly quality – \( F_i \).

Then the technical condition of the SPP object can be described by the functional

\[
TC_i(t) = f(X_{pi}, Z_i, F_i, t).
\]

(1)

The nature of parameters change of the objects' technical condition of SPP should be considered at the organization of their operation. Knowledge of the laws of change of these parameters is of great practical importance, because it allows determining not only the optimal timing of maintenance and repair.

In accordance with the requirements of the system analysis for the most reliable description of the system (in our case, SPP in terms of its technical condition), the system is conditionally "divided" into subsystems (components) of different hierarchical levels, and the lower the hierarchical level of the subsystem, the easier to enter its the structural parts and vice versa.

At the first hierarchical level we placed the main elements of SPP: main and auxiliary internal combustion engine with an index of the technical condition \( TC_{ICE} \), reverse-gear transmission with an indicator of the technical condition \( TC_{RGT} \), uncoupled and elastic couplings between the engine and reverse gear and reverse gear and running water, and clutch shaft with increased technical-state of \( TC_{CE} \), bearings of the shafting with an index of the technical condition \( TC_{BR} \), propellers with an index of the technical condition \( TC_{PR} \).

The elements of the electric power plant (EPP) are placed on the second hierarchical level – generators, shafts generators, cable routes, switchboards and other facilities EPP – with an index of the technical condition \( TC_{EPP} \).

At the third hierarchical level there are ship systems and fire extinguishing systems with an indicator of technical condition \( TC_{FS} \).

At the fourth hierarchical level there are autonomous boilers and secondary heat utilizers with indicators of technical condition \( TC_{AB} \) и \( TC_{HU} \).

The technical condition of the SPP (numerical assessment of the considered SPP property) is established by the method of system synthesis, which in our case can be realized by "convolution" at each hierarchical level of the numerical values of the technical state estimates, hereinafter referred to as the levels of estimates, the structural parts of the subsystem of a lower hierarchical level.

The computer model of diagnostics of objects of SPP will include constructions which final purpose is formation of indicators (criteria) of technical condition \( TC_{ICE} \), \( TC_{RGT} \), \( TC_{CE} \), \( TC_{BR} \), \( TC_{PR} \), \( TC_{EPP} \), \( TC_{FS} \), \( TC_{AB} \), \( TC_{HU} \).

Each indicator of the technical condition can be represented as a function of technical condition specific indicators of the object subsystem. Let us consider in more detail the technical indicators of SEU objects on the example of the most complex of them – ICE.

The system approach to describe the technical condition of the engine is illustrated in figure 1, where all engine subsystems are depicted in accordance with their ranking at six levels. Each subsystem is characterized by its indicator of technical condition. Ranking by levels can be carried out on the basis of expert assessments. According to the results of the expert survey the indicator of the technical condition of the ICE can be represented as a function of the private indicators of the technical condition of the subsystems:

\[
TC_{ICE} = f(S_{iPER}, S_{iCP}, S_{iPS}, S_{iCPG}, S_{iCR}, S_{iLOS}, S_{iCS}, S_{iTC}, S_{iE}),
\]

(2)

where \( S_i \) — the specific indicators of a technical condition ICE: performance \( (S_{iPER}) \), in-cylinder processes \( (S_{iCP}) \), fuel supply systems \( (S_{iPS}) \), cylinder-piston group \( (S_{iCPG}) \), crankshaft \( (S_{iCR}) \), lubrication and cooling systems \( (S_{iLOS}) \), control system \( (S_{iCS}) \), turbocharger's \( (S_{iTC}) \), environmental performance \( (S_{iE}) \).
Each particular indicator of the technical condition depends on a group of parameters, that is, on a certain number of criteria. In this regard, we consider the problem of multi-criteria analysis, one of the ways of solving it is to reduce the set of criteria to one (convolution of criteria). Since all the parameters, which the particular indicators of technical condition depend on, have their importance (weight), it is advisable to use the convolution equation that takes into account this importance. To
solve this problem, we will use a multiplicative strategy of convolution of partial indicators, as a result the objective function is represented by the product of private criteria, the weight of each being ranked by the weighting coefficients, represented as indicators of the degree of particular criteria. It is clear that the greater the weighting factor, the more importance is attached to the criterion. The use of multiplicative convolution in our problem is explained by its high sensitivity to the values of particular indicators – low values of at least one particular criterion lead to a sharp decrease in the objective function. This fact is recognized by the expert community as very important one for the system description of the facilities technical condition.

Thus, each particular indicator can be represented as functions:

\[
S_{\text{PER}} = X_1^{a_1} \cdot X_2^{a_2} \cdot X_3^{a_3}; \\
S_{\text{CP}} = X_4^{a_4} \cdot X_5^{a_5} \cdot X_6^{a_6} \cdot X_7^{a_7} \cdot X_8^{a_8}; \\
S_{\text{FS}} = X_9^{a_9} \cdot X_{10}^{a_{10}} \cdot X_{11}^{a_{11}} \cdot X_{12}^{a_{12}} \cdot X_{13}^{a_{13}}; \\
S_{\text{CPG}} = X_{14}^{a_{14}} \cdot X_{15}^{a_{15}} \cdot X_{16}^{a_{16}}; \\
S_{\text{CR}} = X_{17}^{a_{17}} \cdot X_{18}^{a_{18}}; \\
S_{\text{LOS}} = X_{19}^{a_{19}} \cdot X_{20}^{a_{20}} \cdot X_{21}^{a_{21}} \cdot X_{22}^{a_{22}} \cdot X_{23}^{a_{23}} \cdot X_{24}^{a_{24}}; \\
S_{\text{CS}} = X_{25}^{a_{25}} \cdot X_{26}^{a_{26}} \cdot X_{27}^{a_{27}} \cdot X_{28}^{a_{28}}; \\
S_{\text{TC}} = X_{29}^{a_{29}} \cdot X_{30}^{a_{30}} \cdot X_{31}^{a_{31}} \cdot X_{32}^{a_{32}} \cdot X_{33}^{a_{33}}; \\
S_{\text{IE}} = X_{34}^{a_{34}} \cdot X_{35}^{a_{35}} \cdot X_{36}^{a_{36}},
\]

where \(X_1 \ldots X_{36}\) – the scaled values of indicators of the technical condition of the internal combustion engine, which are a function of the parameters controlled by the sensors installed on the vessel; \(a_1 \ldots a_{36}\) – weighting factors that take into account the influence of the controlled parameters on the technical condition of the SPP facilities.

In a similar way, using a multiplicative convolution, the integral indicator of the technical condition of the internal combustion engine can be represented as:

\[
TC_{\text{ICE}} = S_{\text{PER}}^{b_1} \cdot S_{\text{CP}}^{b_2} \cdot S_{\text{FS}}^{b_3} \cdot S_{\text{CPG}}^{b_4} \cdot S_{\text{CR}}^{b_5} \cdot S_{\text{LOS}}^{b_6} \cdot S_{\text{CS}}^{b_7} \cdot S_{\text{TC}}^{b_8} \cdot S_{\text{IE}}^{b_9},
\]

where \(b_1 \ldots b_9\) — weighting factors, taking into account the impact of private indicators SI on the generalized indicator TC_{ICE}.

It is important to emphasize that all particular indicators and weighting coefficients are dimensionless. Similarly, there are indicators of technical condition \(T_{\text{RGT}}, T_{\text{PR}}, T_{\text{EPP}}, T_{\text{FS}}, T_{\text{AB}}, T_{\text{HU}}\).

Thus, a computer model of diagnosing the technical condition of the SPP should include a model for the definition of private indicators of the technical condition \(TC_{\text{ICE}}, T_{\text{RGT}}, T_{\text{PR}}, T_{\text{EPP}}, T_{\text{FS}}, T_{\text{AB}}, T_{\text{HU}}\). Then the numerical assessment of the technical condition of the SPP can be determined using the following model:

\[
TC_{\text{SPP}} = TC_{\text{ICE}}^{C_1} \cdot TC_{\text{RGT}}^{C_2} \cdot TC_{\text{EPP}}^{C_3} \cdot TC_{\text{HC}}^{C_4} \cdot TC_{\text{FS}}^{C_5} \cdot TC_{\text{AB}}^{C_6} \cdot TC_{\text{HU}}^{C_7},
\]

where \(TC_{\text{SPP}}\) – generalized quantitative indicator of the technical condition of the SPP; \(C_1 \ldots C_9\) – weighting coefficients taking into account the influence of the technical condition of SPP objects on the generalized indicator obtained by the method similar to the one described above.

3. Conclusion

The authors of the article developed special methods of scaling, expert survey and processing the results of this survey. On this basis, a computer model for diagnosing the SPP was created and an electronic calculator of the technical condition of the SPP was developed.

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