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Classification of Electric Propulsion Installations of the Ship Propulsion Systems

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Abstract

There was developed the classification that to the fullest extent covers the classification features of the ship electric propulsion installations (EPI), is used as the means for establishing the relations and updated orientation in their quantitative and functional variety, expresses the system pertaining to the represented actual state of the ship EPI, provides for their recorded properties and relations, prerequisites for correct forecasting of the main fields of development.

Keywords: propulsion generator, electric propulsion installation, electric propulsion engine, classification features, prime mover, propulsion system.

1. INTRODUCTION

It is known that in many cases, the science and technology development is directly related to the results of the performed researches on the basis of collection, processing and analysis of the facts to be ranked and systematized (classified).

Generally, the EPIs belong to the most powerful and separate ship electric drives (ED) having a number of specific features as compared with the common ship electric drives the developed classification of which is given in [1].

Currently, the EPIs are classified according to a number of features provided in the scientific and technical literature that can be conditionally combined in two groups: common and unrelated. Due to the development and implementation of the modern advances, the development of the EPIs of the ship propulsion systems (PS) and their components (main current circuits, control systems (excitation, safety, block and alarm systems)) has led to the necessary correction of and add-ons to the existing classification features.
The classification that is generally a method of inquiry and provides for making progress for the ship EPIs characterized by their increased variety based on the scientific and technical solutions, by the expanded range of capacities and functions, is becoming a forced necessity.

For more profound analysis of the experience in operating the ships with the EPIs as the part of the PS and for solving the tasks set and aimed at their further progressing development, the development of the classification features providing for grouping the ship EPIs and their components by specific distinctive features was among the top priorities.

2. METHODS

One of the first classifications was the EPI classification developed in the late 1950s by V.I. Polonsky [2] according to which it was offered to classify the EPIs by:

- kind and system of current (for example, three-phase (two-phase) direct current instillations);
- type of prime movers (drive motor (turbo-electric propulsion installations (TEPI), diesel-electric propulsion installations (DEPI) and gas-turbo-electric propulsion installations);
- completeness degree of electrification (standalone, auxiliary, combined).

The standalone EPIs which propulsive screws are rotated only by the electric propulsion motors (EPM) were used, for example, in the "General Hazi Aslanov" tanker (1951), series of ice-breaking vessels "Lena" (1954–56), and other vessels. Currently, the standalone (main) EPIs not excluding the capability of power take-off of the propulsion generators (PG) to supply electric power (EP) to the general ship consumers has become the most popular. They are installed in the ice-breakers (series "Yermak" (1974–76), "Moscow" (2008–2016), etc.), ferry vessels of different purpose (series "Soviet Azerbaijan" (1962–68), "Sakhalin" (1973–92), etc.), and many other electric propulsion ships of various purposes and displacement.

The PG of the auxiliary EPIs operated on the EPM during ship movement, while the EP was supplied by the general ship consumers during anchorage. Such EPIs were installed, as a rule, in the technical fleet (dredgers, crane boats, etc.).

The modern version of the EPIs has the auxiliary function in those cases when the main function of the ship electric power systems (EPS) is to supply the EP to the ED of the machinery [3].

In the combined EPIs, the propulsive screws were rotated both by the drive motors (DM) and electric motors (EM) with the EP supplied from the auxiliary generators and being surplus (free) for them. The combined EPIs are mainly used in the refrigerator and fishery vessels primarily foreign made (Federal Republic of Germany, etc.) [4].

According to [2], in addition, the EPIs could be distinguished by:

- purpose, class and type of vessel (installations on

dredgers, fire and emergency vessels);
- power capacity (low, average and large power);
- coupling of the propulsion EM with screws (with direct or toothed coupling).

In the 1960s, the existing classification features in accordance with the defined areas of the EPI development were changed and added to some extent [4].

The changed classification features were those by:

- kind of current (direct or alternative current);
- type of DM (DEPI, TEPI).

The DC EPIs were used in the vessels required to have high manoeuvrability and relatively frequent reverses (whaling ships, ice-breakers, ferry vessels, etc.), and the AC EPIs were used in the vessels required to have increased ergonomics of the installations.

In many aspects, the type of the DM determined the PS performance indicators as a whole. The DEPIs with the efficiency factor (EF) of the DM (diesel) of more than by 30% higher than the EFs of the other heat engines were, as a rule, used in the small and average displacement ships, and the TEPIs with the EF of the ST (steam turbine) of approximately 25% - in the large displacement ships [5].

The following classification features of the EPIs have become also common:

- by type of EPM (with DC EM, with synchronous EM and asynchronous EM);
- by purpose of vessels (tow-boats, ice-breakers, ferry vessels, crane boats, fishery vessels, etc.);
- by excitation system (with centralized, individual and combined excitation system).

A separate classification feature was represented by the EPIs with the dual kind of current (alternative-direct and direct-alternative) that was later combined with the feature by the kind of current [6].

The conducted analysis of the scientific and technical literature provides for making a conclusion about the lacking uniformity of the classification features of the EPIs of the ship propulsion systems. Irrespective of different approaches to the researches, there is no common classification of the ship EPIs till now that would include the required and sufficient range of the classification features characterizing the peculiarities of separate EPIs to the fullest extent and representing their relation with the other ship EDs. Its development is made difficult by the fact that the represented features are not mutually exclusive by any definition.

To close the gap, it is reasonable to set and solve the task of developing the classification of the EPIs of the ship PS meeting the basic up-to-date requirements.

3. RESULTS AND DISCUSSION

Figure 1 shows the developed classification according to which all the ship EPIs can be divided by functional purpose (cell 1), by degree of use (cell 2), by implementation of power channel (cell 3) and by control channel (cell 4).

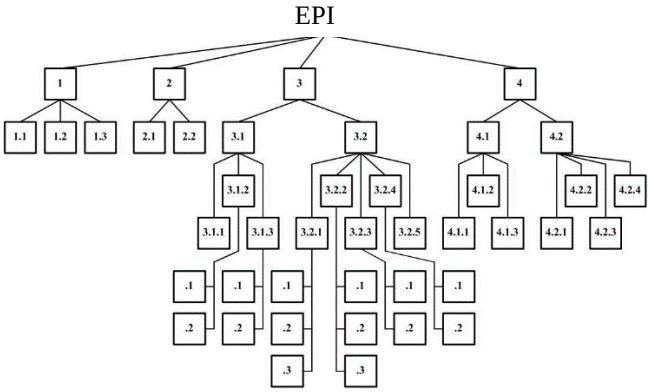

Figure 1. Classification of EPIs of the ship PS

The reasonable quantitative condition for the development of the classification of EPIs of the ship PS was the availability of a cell array on one hierarchic level for the cell of the higher level that made seven maximum, as seven cells constitute, as a rule, the limit of the active perception and analysis of the array of objects by the users.

1. Classification by functional purpose of EPIs.

1.1. Auxiliary.

1.2. Combined.

1.3. Main.

For the auxiliary EPIs (cell 1.1), the power supply for the ship propulsors is the secondary function. Their "drive motor - "DM-PG" generator" systems are designed and chosen, first of all, on the basis of the necessity to supply EP to the main general ship consumers, mainly, the ED of the machinery according to the functional purpose of the ships.

The auxiliary EPIs are used, as a rule, in the technical fleet (dredgers, crane boats, self-propelled drilling rigs, etc.).

The combined EPIs (cell 1.2) represent the component of the mechanical (or hydraulic) and electric methods for the DM power transfer to the ship propulsors (propulsive screws), at this, as a rule, the main ones are the mechanic (hydraulic) transmissions, and the EPIs are designed for power capacity increase on the propulsors in running modes or ships' low-speed movement.

The combined EPIs are used in the fishery and refrigerator vessels primarily foreign made.

The main EPIs (cell 1.3) are designed only for the DM power transfer to the ship propulsors (propulsive screws), and the electric propulsion systems are the main drives of the propulsors. When using the main EPIs, the power take-off for EP supply to the general ship consumers is not excluded.

The main EPIs of the ships are most common and implemented, in particular, in tow-boats, linear and port icebreakers, ferry vessels of various purposes.

2. Classification by degree of use.

2.1. Standalone.

2.2. As the part of single EPS.

For the standalone EPIs (cell 2.1), the ship propulsors (propulsive screws) are rotated by the EPM only.

The standalone EPIs are currently used in major applications of the main EPIs. They are installed in the tow-boats, ice-breakers, ferry vessels and many other types of vessels.

The single ship EPS provide for the EP supply to the general ship consumers and EPM from common buses. The EPIs as the part of the single EPS (cell 2.2) are becoming widely used. Their perspective implementation is closely related to the development of the power semiconductor technology.

The EPIs as the part of the single EPS are used in the supply ships and others.

3. Classification of EPIs by implementation of power channel.

3.1. By structural design.

3.2. By main current circuit.

The classification feature by structural design (cell 3.1) includes the following cell array of one hierarchic level:

3.1.1 – by arrangement and number of propulsors (propulsive screws) (.1 – aftmost, *n*; .2 – aftmost, *n* and foremost, *m* (*n*, *m* – number of propulsors));

3.1.2 – by mechanical coupling of the EPM and propulsive screws (.1 – direct; .2 – by means of transmission devices (couplings));

3.1.3 – by arrangement of EPM (.1 – inside the ship hull; .2 – outside the ship hull).

In the most electric propulsion ships, one or several propulsors (propulsive screws) ($n \geq 1$) are arranged under water at aft of hulls - cell .1 (3.1.1).

In some cases, the propulsive screws are installed at aft and at fore of hulls to improve the manoeuvrability of ships (cell .2 (3.1.1)). Some railroad ferry ships have such classification features, in particular.

Classification feature 3.1.2 (by mechanical coupling of EPM with propulsive screws) includes cells .1 and .2.

Many ships with electric propulsion systems have the propulsors (propulsive screws) with direct mechanical coupling with EPM due to the use of propeller drive shafts (shaft lines) or stub shafts coupling the EPM and propulsive screws – cell .1 (3.1.2).

Using the couplings (cell .2 (3.1.2)) as the transmission devices provides for the advanced feature of the propeller speed adjustment at the constant speed of the EPM shafts.

By arrangement, the EPM can be inside the ship hulls (cell .1 (3.1.3)) that is characteristic for the most ships with electric propulsion systems or outside the ship hulls (cell .2 (3.1.3)) when the EPM are integrated into the underwater parts of pods of the main pod drives.

By main current circuit (cell 3.2), the EPIs are classified by:

3.2.1 – by kind of current (.1 – direct current; .2 – alternative current; .3 – dual kind of current);

3.2.2 – by type of power sources (.1 – electromechanical; .2 – electrochemical; 3 – others);

3.2.3 – by type of EP converters (.1 – analogue; .2 – discrete);

3.2.4 – by number of loops of the main current circuits (.1 – single-loop; .2 – multi-loop);

3.2.5 – by number of operation modes.

In the DC EPIs (cell .1 (3.2.1)), the main DC electrical machinery (EMach) (PG and EPM) are connected in the main (nominal) and partial modes, as a rule, according to the "generator – motor" system.

The DC EPIs are primarily used in tow-boats, linear and port icebreakers, ferry vessels of various purposes and other types of the electric propulsion ships.

In the AC EPIs (cell .2 (3.2.1)), in the most cases, the synchronous generators are used as the PG, and the asynchronous or synchronous EMs are used as the EPM. The main current circuits of some AC EPIs contain the semiconductor EP converters that provide for adjustment of the angular velocity and reverse of the EPM.

The AC EPIs are installed and operated in the passenger-carrying crafts, refrigerators, various transport and other vessels.

The dual current EPIs (cell .3 (3.2.1)) include the alternative-direct and direct-alternative current EPIs.

The synchronous PG and DC EPM are used in the alternative-direct current EPIs, and the main EP sources in the direct-alternative current EPIs are the accumulator batteries (AB) or electrochemical generators, and the asynchronous or synchronous AC EMs are used as the EPM. In both cases, the semiconductor converters (controlled rectifiers, frequency inverters, etc.) are connected between the main EP sources and EPMs to ensure agreement, conversion and adjustment of input and output coordinate values.

The dual current EPIs are now used in ice-breakers, ferry vessels, supply ships and others.

Depending on the modular construction of the electromechanical power sources (cell .1 (3.2.2)), the EPIs are divided into diesel-electric propulsion installations (DEPI) and turbo-electric propulsion installations (TEPI). The use of gas-turbo-electric propulsion installations is not excluded.

The DEPIs installed in tow-boats, linear and port icebreakers, ferry vessels and many other types of ships have become the most widely used.

For the ships with EPIs, it is reasonable to use the TEPIs for large power capacities, particularly, the nuclear ships.

The electrochemical power sources for classification feature 3.2.2 of the EPI given in cell .2 include, first of all, the AB and electrochemical generators.

The scope of application of the EPIs with the electrochemical power sources are, primarily, the low-displacement boats, the coastal passenger ferries, in particular.

The other power sources for classification feature 3.2.2 of the EPI given in cell .3 should, first of all, include the perspective developments related to the use of the wind, sun and other energy.

By type of the EP converter (cell 3.2.3) in the power channel, the EPIs are classified into analogue (cell .1) and discrete (cell .2).

The analogue EP converters include, first of all, the controllable rectifiers, frequency inverters, etc.

The discrete converters include the disconnectors, switches and other mechanical switching devices installed in the main current circuits ensuring a set of circuit loops by switching on and off and sending of discrete voltage values to the EPM winding.

By number of loops of the main current circuits (cell 3.2.4), the EPIs are classified into single-loop (cell .1) and multi-loop (cell .2).

In addition, the EPIs are classified by number of operation modes (cell 3.2.5) created by the power channels by means of control response.

4. Classification of EPIs by control channel.

4.1. By technical implementation of excitation systems.

4.2. By type of power sources of control channel circuits.

The classification feature by technical implementation of excitation systems (cell 4.1) includes the following cell array of one hierarchic level:

4.1.1 – individual;

4.1.2 – centralized;

4.1.3 – combined.

The individual systems (cell 4.1.1) provide for the presence of the separate excitation systems for each main electrical machinery, group of single-functional electrical machinery, separate loops of the main current of the ship EPIs.

For the centralized systems (cell 4.1.2), all the main electrical machinery of the EPIs is controlled by direct interaction (in a centralized manner).

The combined systems (cell 4.1.3) represent various mutual combinations of individual excitation systems.

By type of power sources of control channel circuits (cell 4.2), the EPIs are classified as follows:

4.2.1 – direct;

4.2.2 – electromechanical;

4.2.3 – static;

4.2.4 – others.

The direct ones (cell 4.2.1) provide for power supply to the EPI control channels directly from the general ship consumers.

In the electromechanical systems (cell 4.2.2), the functions of power sources of control channel circuits are ensured by the electromechanical converters which DMs are powered by the general ship consumers.

In the static systems (cell 4.2.3), the functions of power sources of control channel circuits are ensured by the static EP converters.

The others (cell 4.2.4) include the power sources of control channel circuits that are different from those represented in cells 4.2.1…4.2.3, particularly, the AB, electrochemical generators and other power sources.

4. CONCLUSION

1. The scientific-technical literature and educational materials was reviewed and analysed, and according to the results, it was concluded about the lacking uniformity of the classification features of the ship EPIs. There is no common classification till now that would include the acceptable range of the classification features characterizing the peculiarities of separate EPIs to the fullest extent. The relation with the other ship EDs is not represented.

2. The classification features combining the ship EPIs by specific design and operation peculiarities and reflecting the specificity of separate EPIs to the fullest extent, their relation with the other ship Eds, and considering the critical property of actual absence of strict differentiations between separate groups of the EPIs were offered.

3. The classification offered on the basis of the theoretical understanding of the variety of facts does not deny but adds to the existing ones specified in the national and foreign sources. It promotes for development of the ship EPIs from empiric accumulation of knowledge to system approach and theoretical synthesis.

4. The developed classification of EPIs is a natural dynamic classification that is made by substantial kind-forming features and provides for bringing the entire variety of the ship EPIs to a small number of groups, and thus simplifies the study, technical improvement and further understanding of their development, promotes for the formation of the more substantiated approach to the development of the theory and practice of the ship EPIs. The offered classification does not deny but adds to the existing ones specified in the national and foreign sources. It promotes for development of the ship EPIs from empiric accumulation of knowledge to system approach and theoretical synthesis. It stimulates the development of the theoretical aspects of researches, provides for substantiated forecasts regarding the unknown facts or objective laws, is a quantum leap in their development.

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