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O. Glazeva, PhD.,
V. Busher, ScD.,
V. Vlasov

MODERN LINES OF DEVELOPMENT OF SHIP ELECTROMOTIVE SYSTEMS

Abstract. *A comparative analysis of the main types of modern ship power systems has been made. Presented are the basic advantages of the propulsion electric units – increase of manoeuvrability, transhipment ability, efficiency, reliability and noise reduction. The main directions of development of marine electrical power systems – the use of high-voltage electrical machines, controlled-speed drives for synchronous and asynchronous motors, and valve-inductor motors with permanent magnets are determined. As the most promising, power cryogenic plants and machines with high-temperature superconductors are highlighted.*

Keywords: *electric propulsion system, unified electric power system, electric propulsion engine, fixed pitch propeller, controllable pitch propeller, high-voltage equipment, and high-temperature superconductor*

О. В. Глазева, канд. техн. наук,
В. В. Бушер, д-р техн. наук,
В. Б. Власов

СОВРЕМЕННЫЕ НАПРАВЛЕНИЯ РАЗВИТИЯ СУДОВЫХ ЭЛЕКТРОДВИЖУЩИХ УСТАНОВОК

Аннотация. *Проведен сравнительный анализ основных типов современных энергетических судовых систем. Показаны основные преимущества гребных энергетических установок с электродвижением – повышение маневренности, перегрузочной способности, КПД, надежности, снижение шума. Определены основные направления развития судовых электроэнергетических систем – применение высоковольтных электрических машин, регулируемых приводов для синхронных и асинхронных двигателей, вентильно-индукторных двигателей с постоянными магнитами, машин с высокотемпературными сверхпроводниками.*

Ключевые слова: *система электродвижения, единая электроэнергетическая система, гребной электродвигатель, винт фиксированного шага, винт регулируемого шага, высоковольтное оборудование, высокотемпературный сверхпроводник*

О. В. Глазєва, канд. техн. наук,
В. В. Бушер, д-р техн. наук,
В. Б. Власов

СУЧАСНІ НАПРЯМИ РОЗВИТКУ СУДНОВИХ ЕЛЕКТРОРУШІЙНИХ УСТАНОВОК

Анотація. *Проведено порівняльний аналіз сучасних енергетичних судових систем. Показано переваги суднових енергетичних установок з електрорухом – підвищення маневреності, перева-нтажувальної здібності, ККД, надійності, зниження шуму. Визначено головні напрями розвитку суднових електроенергетичних систем – використання високовольтних електричних машин, регульованих приводів для синхронних і асинхронних двигунів, вентильно-індукторних двигунів з постійними магнітами і машин з високотемпературними провідниками.*

Ключові слова: *система електроруху, єдина електроенергетична система, електродвигун, гвинт фіксованого кроку, гвинт змінного кроку, високовольтне обладнання, високотемпературна надпровідність*

Introduction. In recent decades, special purpose ships whose hallmark is a wide range of changing the ship's speed, and continuous operation in the modes of maneuvering and dynamic positioning have become widespread. The special feature of operating such type of ships' propulsion systems is the change of rotation frequency and load in a wide range. The accumulated experience in the design and operation of ships allowed moving to a new class of ship energy based on electric propulsion systems (EPS).

The aim of this work is to review contemporary perspective directions of marine electrical and power equipment development allowing by their integration into the unified power systems to minimize operating costs, weight and size parameters, and optimize other consumer properties of vessels and ships.

Research materials. Implementation of the goals of creating a low-noise, reliable, cost-effective, providing for high maneuverability and full-variable propulsion electric unit (PEU) inevitably leads to the idea of using the "electric propeller shaft" in it. This enables the installation to operate without the gear, the part with most active vibration, significantly reduce the length of the shaft, simplify the design of the main turbine and provide favorable conditions for its operation. Ship electric propulsion units (SEPU) are designed to provide the ship's motion in all running conditions.

Compared to conventional propulsion systems based on the use of heat engines (diesel engines and turbines), SEPU have a number of advantages:

– enhancing the ship's maneuverability performance due to the best adjustment characteristics;

– the ship's ability to work in complex ice conditions due to high transshipment ability;

– reduction in fuel consumption due to a high coefficient of performance during operation with partial loads;

– possibility of optimal placement of equipment in the premises of the vessel;

– high reliability of electric power installation as a whole;

– good vibration and sound characteristics; and

– reduction of harmful operational emissions into the atmosphere.

The main disadvantages of the ships using electric propulsion include increase of the equipment composition; and ship's cost increase.

At the same time, the increase in weight and size indicators can be compensated by the rational placement of equipment in the engine room – not horizontally, but vertically, when the diesel generators are placed on a platform, propulsion motors – beneath them in the hold because communication is performed not through the shaft line, but through the cable one. This reduces the length of the ship and, accordingly, cuts the consumption of metal when building the hull, and reduces the ship's weight.

SEPU comprises the following:

– propeller;

– propulsion electric motors (PEM);

– semiconductor converters;

– power transformers;

– switchboards: MSB, EMB;

– integrated control system; and

– generating units.

The propulsive devices applied in the SEPU composition are propellers or azimuthally rudder propellers (ARP).

Propellers have become quite widespread as the main propulsive devises because of their simplicity and high efficiency, as well as due to their ability to provide for high coefficient of efficiency when using the fixed pitch propellers (FPP). Owing to these advantages FPP are used on most transport ships. However, FPP requires a very definite rated mode of operation, for which its characteristics ensuring the highest efficiency are determined. In other modes, the propeller becomes unable to use the full power of the drive motor.

As a more rational option of ensuring the operation of propulsion system is the use of controllable pitch propellers (CPP). Their undoubted advantage is that they allow for the drive motor operation in the rated mode under virtually any conditions of navigation by changing the angle of rotation of the blades. However, the efficiency of the CPP in the nominal mode is always less than the same of FPP.

The main versions of the applied EPS schemes include synchronous motors operating for the fixed pitch propeller (FPP) with rotation speed control via frequency converters, thyristor converters and DC motors, asynchronous squirrel-cage motors with thyristor voltage converters for soft start or frequency converters, and a combination of a controllable pitch propeller (CPP) with variable-frequency electric motor (Fig. 1).

Asynchronous motors with short-circuited rotor in combination with a frequency converter or DC electric motors with uncontrolled rectifiers or controlled voltage converters may be used in propulsion installations of small and medium power (1 ,..., 5 MW) as PEM.

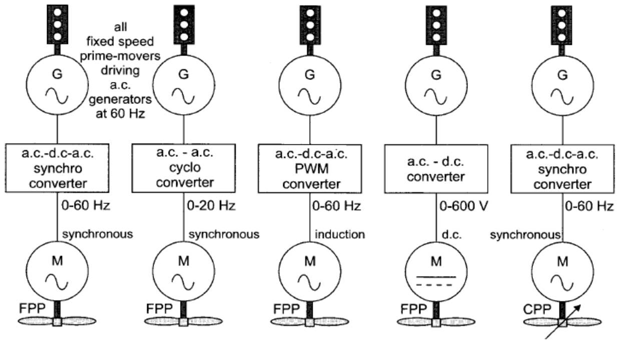

Fig. 1. Electric propulsion options

As the drive motors of generators fixed-speed diesels are mostly used.

With a view to more efficient use of PEU equipment, simplification of its maintenance, improved fuel economy and an increase in ship's cargo tonnage, the development of EPS has gone along the way of joining the power supplies of PEU and all other ship's consumers into the unified EPS (UEPS).

The composition of UEPS may include power converters of various types:

– mechanical – with direct drive to the propeller;

– electrical (frequency converters and controlled rectifiers);

– a combination of mechanical and electrical converters.

Traditionally, the propeller shaft is directly connected with the propulsion electric motor, which is located inside the vessel. But the experience of operating a number of support vessels, and ice breakers especially, on which PEMs are located outside the ship's hull (electric RP) has demonstrated the great advantages of the so-called AZIPOD, in which the mobile pod generally mounted under the ship's hull and housing PEM can rotate in any direction through a full 360 degrees with the application of the propelling force. This eliminates the traditional steering systems and stern thrusters. At the same the maneuverability of the ship and its cargo-passenger capacity are considerably increased, while the vibration of the ship is reduced.

Currently, a new type of EPS on the basis of circular-design propulsion-drive systems with submersible electric drive (CDPDS) is being created. The fundamentally new element in CDPDS as compared with other types of RP is a circular-type submersible PEM combined with propeller. Due to the integration of the engine and propeller into a single structure; in contrast to the traditional mechanical RP with Z- and L-type transmissions, CDPDS require no heavy shafts and complex, expensive, bulky bevel gear speed reducers.

Unlike traditional EPS, a synchronous machine with permanent magnets is applied in CDPDS as PEM. This increases the coefficient of efficiency, improves reliability and reduces the dimensions and weight of CDPDS.

As opposed to the electrical AZIPOD-type RP, the PEM body in CDPDS does not inhibit the flow of water during operation of the propeller, since the latter is located inside the hollow rotor. Using CDPDS of such design greatly increases the hydrodynamic efficiency of the EPS in whole.

It is promising to use valve-induction motors (VIM) as PEM. As compared with synchronous motors with solenoid excitation or with excitation from permanent magnets, VIMs are structurally simpler and more reliable, and their cost is lower. Concerning the main operation characteristics they are equal to high-efficiency valve engines with permanent magnets. High reliability of the VIM power inverter should be noted, which is caused by the circuit-design decisions that exclude the possibility of short circuits in the inverter.

Since the power consumption on ships steadily increases, there is a practically realized need to use high-voltage systems in order to ensure the ship requirements (3.3 kV, 6.6 kV or 11 kV). The generation of electricity under the standards of high voltage is more advantageous than the standard 440 V, 60 Hz. Thus, a tenfold increase of the voltage results in a tenfold reduction of the nominal current and short-circuit currents, and losses – dozens of times. Therefore, the issue of desirability of high voltage application on modern electric ships is not debatable, it is obvious.

A special place is occupied by EPS in naval shipbuilding. The use of full electric propulsion for the ships with a displacement of about 2,000 tons, which have gas turbine engines (GTE) as a part of their EU is possible in the production of for the new technical level components – complex-cycle GTE, high-voltage equipment (6000 ,…, 12,000 V), etc.

An example may be set by the characteristics of EU of British Navy destroyer "Daring" (Type 45). The primary power sources with a voltage of 4.16 kV and power capacity of 21 MW are energised by GTE WR21 with complex cycle. The generators are combined by the electric network and through the frequency converters supply a power of 20 MW to PEM connected to the propeller shaft lines (Fig. 2).

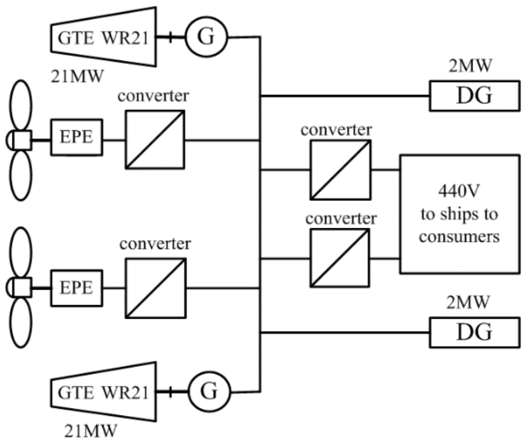

Fig. 2. Diagram of EU with complete electric propelling of Destroyer *Type* 45

However, at high speeds (of up to 16 ,…, 18 kt) the noise advantage of electric propulsion is lost because the main source of the underwater noise are screw propellers. As a result, EU with partial electric propulsion, which combine thermal engines with high power density (GTE) and high-voltage PEM (for example, GODLOG scheme), in which at speeds of up to 16 ,..., 18 kt PEM work supplied with power from the ship's power plant through EPS with frequency converters, and at higher speeds – GTE with reduction gears and Controlled-pitch propeller.

The use of electromagnetic force for electrical propulsion of ships is also of great interest. As a result of interaction between the current and magnetic flux in the conductor (sea water) there appears a mechanical force that creates a linear focus for the movement of the vessel. In this case there is no need to apply a rotating screw. Dividing the propulsion pipes (thrusters) into short sections along the ship's hull enables abandoning of the traditional steering and thrusters. However, the main gain is in the unprecedented freedom in the ship's design: the diesel engines or turbines may be placed without a hard peg to the propeller shaft.

The latest trend in high-power energetics for large-capacity ships is the use of cryogenic plants (CP) and high-temperature superconductors (HTS) working at the temperatures of liquid nitrogen. The new generations of motors and generators operate with their coils being cooled to very low temperatures, which significantly reduces resistance (about 15 times in CP for aluminum and copper windings) or the latter is equal to zero (in machines with HTS). Under such conditions, the electrical losses (I^2R) are reduced 5 ,…, 10 of times, and the windings of electrical machines with a small cross section of wires can carry extremely high currents. The weight and dimension parameters of electric machines and transformers are decreased 2,5 ,..., 3 times. The use of frequency converters with a link of direct current for all ship's consumers (e.g. as in Fig. 3) it also becomes possible to use high-frequency generators with optimal frequencies in a range of 250 ,..., 500 Hz, which together with CP or HTS allows to reduce the weight of electrical machines 5,5 ,..., 6 times, and reduce the overall losses 10 ,..., 25 times [6; 10].

Conclusions. Based on the stated above, we can predict the further development of SEES in the following main areas:

– usage of high voltage;

– introduction of superconducting electrical machines;

– increase of the generators capacity and load;

– improvement of the structure of EPS and electrical equipment;

– usage of different types of controlled electric drives.

Complication of SEES requires a wide application of computer systems for the automated management of the EPS and PEU, technical diagnosis, protection and control. When designing and building the vessels with electric propulsion an integrated approach is required to ensure the interconnection of the main functional elements (PEM, RP, FC, etc.) taking into account the tasks faced by the ship.

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Busher
Victor, Doctor of Technical Sciences, Professor, Department of Electromechanical Systems with Computer Control, Odessa National Polytechnic University, 1, ave. Shevchenko, Odessa, Ukraine, 65044.
Contact tel.: +38(050)3908809.
E-mail:
victor.v.bousher@gmail.com

Glazeva
Oksana, Ass. professor, Candidate of Technical Science, Department of Ship's Electromechanics and Electrical Engineering, Odessa National Maritime Academy, 8, Didrikhson str., Odessa, Ukraine, 65029.
Contact tel.: +38(067)9940342.
E-mail: Glazeva@bk.ru

Vlasov Victor,
Prov. Engineer, Department of Ship's Electromechanics and Electrical Engineering, Odessa National Maritime Academy, 8, Didrikhson str., Odessa, Ukraine, 65029