

# Electric Drives on Ships of the Russian Fleet

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**Abstract**— *Electric drives (ED) are the main consumers of ship electrical energy. On the ships of the domestic fleet, in most cases, alternating current electric drives are used. The main components of the power channels of ED are electromechanical converters (EMC) – electric motors (EM), which in the general case convert electrical energy into mechanical energy or perform the inverse transform. A characteristic feature of ship EM is their wide variety. The output coordinates EM are torque (or linear force) and angular or linear speed. The subject of the present work is the study of ship ED to determine the main variants of used EM. The obtained results allow for more appropriate emphases in the study of electric machines in the process of preparing of specialists for Maritime transport.*

**Keywords**— *Electromechanical converter, ship electric drives, electric equipment, ship mechanisms, electric motor.*

## I. INTRODUCTION

EM of ship ED are the main consumers of ship electric energy. Back in the mid-twentieth century, their number on ships amounted to hundreds of units of various capacity and execution. For example, on a passenger vessel German built "Alexander Pushkin" (of series "Ivan Franko") from 744 consumers of electric power 555 are ED with a total power of 4445 kW [1]. In general, according to the data given in [2], ship ED consume up to 90 % of the electricity generated by ship generators.

Conditions of operation of ship electrical equipment (EE) including EM are specific and differ greatly from coast conditions [3]. They are exposed to climatic and mechanical effects in a wide range.

Technical characteristics and major requirements to ship EM determines Russian maritime register of shipping and classification societies of other countries.

In accordance with the developed classification [4], ship ED on modes of work can be grouped in three main groups.

The first group includes ED, modes of work which coincide with the continuous and intermittent nominal modes (S1 and S6, respectively). These include, generally, unregulated ship's ED (steering, ship's blowers of machine systems and, etc.).

The second group includes ED, which have the modes close to the short-term nominal regimes of the symbol S2. Such drives in many cases different more severe conditions of operation in transient modes of operation. Examples of the second group are some ED ship hoisting machines (SHM) of a general ship purpose, machine lifts, anchor-mooring mechanisms (AMM), etc.

The third group includes ED, whose modes of operations are close to intermittent (S3), with frequent starts (S4) and electric braking (S5), the alternating nominal regimes with

frequent reverses (S7) and with two or more angular speeds (S8). Thus, because of the specific operational features, primarily due to the wide range of climatic, mechanical and chemical loads, along with the general requirements to ship's ED, for each individual group, which includes ED in accordance with the developed classification, must determines complex of separated requirements. Requirements for ship's ED is dictated by the operating conditions, identify the relevance of improving an efficiency of their functioning.

## II. RESEARCH

The majority installed on vessels of domestic and foreign manufacturer ED first group include EM and relatively simple control systems (CS). The requirements of such ED to correspond EM direct current (DC) "PM" series, three phase asynchronous motor (AM) series "4A" [5], single-speed AM of a series "MAP". Motors "PM" series are sea a modification of a single of a number of domestic generic EM DC series "P". Three-phase AM series "4A" replace EM series "AO2-M" [6].

EM DC "PM" series implemented basic structural principle – minimum mass per unit nominal torque. They include 11 dimensions and cover a power range from 0.1 kW to of 210.0 kW at the nominal angular speed (frequency of rotation) (78.6...314.2) rad/s ((750...3000) rpm). EM "PM" series allow continuous operation at voltages up to 320 V. The service life of these motors is up to 12000 hours.

Three-phase AM of "AO2-M" series are a modification of the single series of EM "AO2". Main technical data of motors series "AO2-M" are given e.g. in [7].

Three-phase AM series "4A" includes 25 dimensions with a power range from 0.1 kW to 315,0 kW at rated of frequency rotation (600...3000) rpm. They are made for voltages 220 V, 380 V and 660 V. A connection circuits of the stator windings EM in a "star" or "triangle". When you work EM in short-time modes the power can be increased by 25% when work time 30 min and by 10 % at work time 10 min. They allow continuous operation at reduced frequency up to 65 % of the nominal when proportional voltage reduction and stop under starting current for 10 seconds with the set temperature. The service life of these EM reaches 20000 hours.

In addition, minimal moments of AM series "4A" are not less than 90 % from the nominal values.

Three phase single speed AM of series "MAP" meet requirements of the International Electro Technical Commission (IEC). Power range single-speed motors series "MAP" is in the range (1.2...90.0) kW at rated frequency of rotation from 880 rpm to 1475 rpm. Their technical data is given in [6].

CS of modern ship's ED of relatively large (comparable) power, which include well as AM with squirrel-cage rotor windings, realize, as a rule, start up of EM at reduced voltage (a way to switch from "star" to "triangle", using systems "voltage regulator – asynchronous motor" (VR–AM), etc.) [8]. Start up powerful ship's ED, which include AM with of phase windings rotor, carried out mostly by the connection of additional resistance in the rotor circuit.

In most installed on ships of domestic and foreign built reversible adjustable multi speed ED of the second and third groups are comprised of electromechanical converters (EM) DC or alternating current (AC) and various technical and schematic solutions of CS.

In ship ED DC these groups have found application EM DC parallel (independent) or mixed excitation. One of the main advantages of these ED is the ability to smoothly and widely to adjust angular speed of a motor shaft. ED DC the sequential excitation by virtue of their specific features on ships used very rarely.

In domestic ship's ED widely used reversible EM DC short-term and intermittent operation modes of the series "DPM", which are modification of a special series of crane and metallurgical EM. Series "DPM" includes ten sizes (dimensions) EM with disc brakes or without them. The power range of EM is (1.6...95.0) kW at nominal speed of 615 rpm to 1850 rpm. There are two basic variants of EM series "DPM" against the same maximum rotation frequency  $n_{max}$  to the nominal rotation speed  $n_n$  ( $n_{max}/n_n$ ) – high-speed and low-speed. This ratio high-speed EM is two, and low-speed EM equal three. High-speed EM used, as a rule, for ED with number of start-up to 300 per hour, and low-speed – up to 500 per hour. The mass of high-speed EM on (15...20) % less than low-speed EM with the same useful work. Overload capacity on current of motors "DPM" reaches four times the values relative to the nominal currents. EM allow operation at voltages up to 450 V within of overload abilities. EM have a high fatigue strength when the number of start up to  $10^7$  per service life.

For high-power ship's ED (SHM, fishing mechanisms, etc.) used special EM direct current, for example, marine modifications of domestic crane EM series "D800", "DP", etc.

EM of independent excitation series "D800" cover range of powers from 80 kW to 350 kW at the rated speed (900...1000) rpm. They allow operation at voltages up to 600 V. Overload capacity on current these ED is equal to two [6].

Most CS of ship's ED with EM DC contain controller schemes or relay-contactor schemes, systems "generator – motor" (G–M), "control rectifier – motors" (CR–M), etc. [9]. The number of such ship's ED is constantly decreasing due to the decommissioning of obsolete ships, built in the second half of the twentieth century, and in connection with the introduction on most modern ships AC.

Currently most ships are equipped power stations of three-phase alternating current that along with other reasons has predetermined wide use on ships of ED AC.

The hydraulic reversible adjustable ED AC the second and third groups consist of usually one-speed AM with squirrel-cage windings of the rotor and relatively simple relay-contact

schemes. To reverse and regulation of the working speed used variable displacement pumps and valve boxes.

Hydraulic adjustable ED AC the second and third groups installed, for example, on ships of series: "Igor Ilyinsky" (Spain) – in AMM; "Posyet" (Greece) – in AMM and SHM; "Argun" (Romania) – in SHM [10] etc.

When used in ED AC the second and third groups of mechanical reducer transmission devices, the composition of ED includes a multi-speed AM with one or some separate windings of the stator or with poles switchable windings of the stator and with slip ring or squirrel-cage windings of the rotor. CS such ship's ED AC includes a controller or relay-contactor systems, systems "frequency converter – asynchronous motor" (FC–AM), VR–AM and others.

ED with multi-speed AM, which have phase windings of rotor and controller or relay-contactor systems, have found application, for example, in ED of SHM (lifting mechanisms of cranes) on the m/v series "Stakhanovets Kotov" (Finland) [11] and some others.

In most reversible ship's ED with adjustable speed and with a mechanical (geared) transmission devices of the second and third groups installed and operated multi-speed AM, which have a separate or poles switchable stator winding and squirrel-cage windings of rotor [9]. This is due, primarily, with rational solutions for EM in the ratio of numbers of poles stator windings, the multiplicities of the starting and maximum moments, centrifugal masses, etc.

In ship's ED AC a second and third groups widely used a single number of domestic multi-speed of three phase asynchronous squirrel-cage EM with high resistance rotors the series "MAP". These motors matched requirements of IEC.

The basic series of motors "MAP" includes nine sizes. These motors are produced with attached disc brakes or without them. The range of power two-speed EM series "MAP" is within (0.3...100.0) kW at nominal speeds of 385 rpm to 1410 rpm, and of three-speed motors - within (2.5...90.0) kW at rated speeds from 175 rpm to 1495 rpm. The number of starts for EM at service life of 10 years is  $2 \cdot 10^4 \dots 10 \cdot 10^6$  [6, 12].

CS of reversible ED with multi-speed AM contain, in most cases, relay-contactor systems, involving magnetic controllers (magnetic station) and controllers, or controller schemes, which include power controllers [9]. According to the data given in [6], cam controller CS used at an installed capacity of EM to 22 kW, contactless controller CS – to 30 kW, and relay-contactor CS – to 100 kW. Most widely are used relay-contactor CS [13], mainly because of the increasing capacity of ship ED.

Increasing requirements to different ship's ED leads to necessity of search of new technical solutions. Ship's ED came to a new quality level with a development of the theoretical developments and practical implementation of solid-state, microprocessor and etc. of technic.

With 80-ies of the twentieth century was a promising direction the development of ship's ED on the way of expansion of use of asynchronous frequency-controlled ED with squirrel-cage motors [14, 15].

For ship's ED with frequency regulation of speed provided one speed EM, two speeds EM and EM with three speeds of special construction production. Range of power domestic EM a series of "MAP" to variable-frequency ED is (1.2...52.0) kW. One speed EM used in ED with a change of frequency in the range of (5...80) Hz, and two speed EM and three-speed EM – with a change of frequency in the range of (5...20) Hz on winding of a low speed [6, 12].

Variable frequency of ED system FC-AM with thyristor frequency converters of series "SAMI" (Finland), installed, for example, in ED cargo pumps on ships of the series m/v "Grigoriy Nesterenko" (USSR) [10, 16]. A large part of the logic functions CS of ED is done by microprocessors [17]. Systems FC-AM with transistor frequency converters "FREQROL-Z200" (Japan) are part ED production mechanisms of super trawlers type m/v "Sotrudnichestvo" (Spain) [18, 19]. Ship frequency ED system FC-AM on the basis of domestic frequency converters of series "TTS" [20] was installed and tested on a fishing freezer trawler (super) series "Horizont" (USSR). ED systems FC-AM with modifications of domestic frequency converters of series "TTS" is used, for example, in ED of SHM on universal floating base of series "Kamchatsky shelf" – "Tauskiy shelf" (USSR) [18].

In ship's ED began to be used regulators of alternating voltage. For example, in ED of SHM ships of the series "Cheremkhovo" (Germany) [10] installed ED, which includes three-phase asynchronous EM with phase rotors and CS with thyristor regulators of voltage (of system VR-AM) [18].

For research was used effective statistical method, that does not require the cost of creating test stands. On the basis of some General principles of approach to working with ship's statistical material, may be formulated the main principles of approach to working with statistical data. These include: thorough (qualitative) analysis of the collected statistical material for the purpose of extracting the maximum volume of necessary information; mandatory verification of the homogeneity of merged samples from various sources when necessary, combining information in cases of insufficiency of available statistical material one source [9].

According to the results of processing of statistical data on ships of the Far East basin, the total installed active power multi-speed ED  $P_{\Sigma MЭП}$  from the total installed capacity of marine EE  $P_{\Sigma CЭО}$  is: (9.4...35.5) % – ships for transportation of general cargoes; (0.7...27.2) % – ships for transportation of bulk cargoes; (4.4...12.4) % – container ships; (7.2...8.7) % – refrigerated ships. It should be noted, that in addition to drives with multi-speed AM, on some series of ships are used other options multi-speed ED, which was not taken into account.

In table 1 and table 2 shows the main types of multi-speed AM, used in the composition ED of ship's AMM and SHM. In column 3 of table 1 and table 2 listed types of EM, installed on most ships of the series, indicated in the graphs 6, or types of ED, that are installed on individual ships of the series, indicated in the graphs 6 tables in parentheses. At ED of cargo cranes (table 2) in column 3 is listed types of multi-speed AM, which in the lifting mechanisms are use.

Table 1. Types of multi-speed AM with two or three separate or poles switchable windings of stator, which used in EP of AMM

No	Ship mechanisms	Multi-speed AM			Series of ships
		Type	Power, kW	Plant, country of production	
1	Windlasses, anchor spires	1.1. EM of Russian production			
		MAP612-4/8/16	28,0/30,0/10,0	«Dinamo»	«Krymsk», «Pioner Moscow», «Sachalin»
		MAP622-4/8/16	30,0/18,0/10,0	«Dinamo»	«Krymsk», «Pioner Moscow», «Sachalin»
		MAP721-4/8/16	75,0/62,0/18,0	«Dinamo»	«Anatoliy Kolesnichenko», «Norilsk»
		1.2. EM of foreign production			
		AG3155	28,0/56,0	«AEG», Germany	«Vyborg»
		DRO 470-6/4 (with phase rotor)	36,0/13,0	«Elmo Dessau», Germany	«Povenets»
		hABzd527-16/8/4	38,0/85,0/85,0	«Rade Končar», Yugoslavia	«Dubrovnik», «Ivan Kotlyarevskiy», «Pula»
		hPR-1792-168,4D	23,0/55,0/55,0	«Siemens», Germany	«Volgoles»
		hSSDa-28/8/4	3,0/19,0/38,0	«Elmor», Poland	«Nikolay Novikov»
		mZSK11-16/8/4	25,5/70,0/58,0	«Selma», Poland	«Kommunist»
		TOJ-16/8/4	24,5/51,0/51,0	«Hitachi», Japan	«Omsk»
		2	Mooring winches	2.1. EM of Russian production	
MAP621-4/8/24	34,0/15,0/3,0			«Dinamo»	«Norilsk»
MAP622-4/8/24	40,0/20,0/4,4			«Dinamo»	«Samotlor»
2.2. EM of foreign production					
AHLL 318-24/8/4	4,6/19,0/38,0			«Elmo Dessau», Germany	«Wamemunde», «Pskov», «Rostok»
AHLL 359-28/8/4	4,8/24,0/24,0			«Elmo Dessau», Germany	«Irkutsk»
AMW80.78-4/8/28	30,0/15,0/3,5			«Ben Buchelen», Germany	(«Sachalin-7»)
hSSDa-28/8/4	3,0/19,0/38,0	«Elmor», Poland	«Vasiliy Shukshin»		
3	Mooring spires	3.1. EM of Russian production			
		MAP511-4/8/16A	15,0/15,0/4,5	«Dinamo»	«Mirniy», «Pyatidesyatiletie komsomola», «Sibirles»
		MAP521-4/8/16A	12,0/12,0/6,0	«Dinamo»	«Krymsk»
		MAP612-4/8/16	22,0/22,0/7,0	«Dinamo»	«Sachalin»
		MAP621-4/8/16	36,0/22,0/7,0	«Dinamo»,	«Ivan Skuridin»
		MAP721-4/8/16	60,0/55,0/18,0	«Dinamo»	«Norilsk»
		3.2. EM of foreign production			
		KWS250.2/16-8-4	7,4/14,7/7,7	«Wernigerode»,	«Pioner»



	KWS280. 3/16-8-4	12,0/24,0/12,5	Germany «Elektro- din», Germany	«Vyborg»
	mZSK8- 16/8/4	10,0/21,0/17,0	Poland «Selma»,	«Aleksandra Kollontay»

Table 2. Types of multi-speed AM with two or three separate or poles switchable windings of stator, which used in EP of SHM

Multi-speed AM			
Type	Power, kW	Plant, country of production	Series of ships
Cargo winch, cranes			
1. EM of Russian production			
MAP612-6/12/24	32,0/16,0/5,0	«Dinamo»	«Bezhitsa», «Leninskiy komsomol», «Mirniy», «Pyatidesyatiletie komsomola», «Krimsk»
2. EM of foreign production			
AHLL 318-24/8/4	4,6/19,0/38,0	«Elmo Dessau», Germany	«Warnnemunde», «Rostok», «Chudozhnik Sariyn»
DRO 470b-32/8/4M	4,5/22,0/45,0	«Elmo Dessau», Germany	«Dzhankoy», «Povenets»
hABzd505-32/8/4	3,7/19,0/38,0	«Rade Končar», Yugoslavia	«Belomorskles», «Volgoles»
hQOR-212 28/8/4	3,1/19,0/39,0	«Siemens», Germany	«Kotlasles», «Krasnokamsk»
hSSDa/100-28/8/4	3,0/19,0/38,0	«Elmor», Poland	«Aleksandra Kollontay», «Vlas Nichkov», «Kommunist», «Leninskaya gvardiya»
MTV-26/8/4	3,4/19,0/38,0	«Uljanik», Yugoslavia	«Dubrovnik», «Ivan Kotlyarevskiy», «Pula»

Sources of statistical materials on the basis of which to build table 1 and table 2, are technical documents of ships, polls of ship's electric engineers and specialists of technical services of the Far Eastern basin.

In parentheses of tables showed a name of a ship and not series of ships. When is approximate equality number of identical type EM on ships of one series, in tables provided all types of used motors.

### III. CONCLUSION

It is proved that the main consumers are ED, which consumed most of ship's electric energy. The number of EM installed on ships, in many cases amounts to hundreds of units. In ED ship machineries with adjustable working speed are used, as a rule, three-speed AM with separate windings of the stator or with poles switchable windings of the stator and squirrel-cage windings of the rotor.

In ship's ED AMM used three-speed AM, structurally executed as the constancy of the torque on the first and second or second and third speeds, and also with constant power at

the second and third speeds. Power range of EM AMM is (2.6...85.0) kW.

Most multi-speed AM, used in ED SHM, made on the principle of the constancy of a torque on the second and third speeds. The power range of EM, used in ED SHM, is (3.0...45.0) kW.

For qualitative preparation of specialists of various levels for sea transport priority direction should include a study of AM three-phase alternating current.

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