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# Reliability Study of Shipboard Electrical Equipment

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**Abstract:** The research relates to reliability study of shipboard electrical equipment, particularly marine electric motor drives. Based on the operation condition performed research, it was confirmed that reliability which directly may affect the ship running operational safety and cost effectiveness, related to main integrated features of seaboard electrical equipment representing relatively complex technical products. Analytic and experimental researches containing integrated knowing the failures and the marine electric motor drives related to the main shipboard electrical equipment and connected to reliability and effectiveness growth in technical operation were the most solvable problems. Analytic and experimental researches containing integrated knowing the failures and the marine electric motor drives related to the main shipboard electrical equipment and connected to reliability and effectiveness growth in technical operation are the most solvable problems.

**Key words:** Electrical equipment, electric motor drive, reliability, electromagnetic compatibility, Weibull distribution

## INTRODUCTION

The operated domestic and foreign ships are equipped with Electrical Equipment (EE) of different complexity. The operating conditions of Shipboard Electrical Equipment (SEE) are specific and differ considerably from EE operation conditions in other branches. The best part of the ships of various purpose were built and put into operation in the 20th century. Those ships facilities included many obsolete and worn-out electrical equipment systems which technical upgrading potential was practically exhausted or became marginal by the beginning of the 21st century. Their further effective use required fundamental theoretical and operational studies. Proceeding from specific requirements the marine electrical equipment possessed certain clusters of features. The most quality performance indicator was reliability which under otherwise equal conditions, depended on design features, test modes and conditions. The electric motor drives related to main marine electrical equipment constituting a technical product being relatively complex to be repaired. Scientific and technical literature analysis allowed making a conclusion of that subject.

In general, the causes of failures of Shipboard Electric Equipment (SEE) is a family of factors due to its designing, manufacturing and operating conditions.

Shipboard electrical generating plants are stand-alone systems of limited power. It is allowed to use two-wire isolated networks (RMR, 2008) at ships with DC Electric Power Systems (EPS) for terminal voltage of consumers of up to 500 V. It is allowed to use three-wire isolated networks at ships with AC EPS with a frequency of 50 and 60 Hz for terminal voltage of consumers of up to 1,000 V. It is additionally allowed to use four-wire isolated networks for terminal voltage of consumers of up to 500 V. An exception is for example, Mercury catamaran where the “neutral” of the network is connected to the hull (Burkov, 2009). In most cases, three-phase AC EPS are used at modern ships.

The characteristic features of the operating conditions of SEE include aggressiveness of the environment and its changes over a wide range, changes in position and impacts relating to individual parts of EE, due to changes in positions and impacts of the hull; vibration which usually reaches its greatest intensity at the hull ends.

## MATERIALS AND METHODS

Total vibration (oscillation frequency) of the hull is several Hz (Vilesov, 1982) and it does not lead to accelerated failure of SEE but in prolonged exposure contributes to the emergence of deformations including of individual EE components reduction in service life of isolation and disruption of contact connections. Local vibration of separate structures is (2...5) times higher total vibration by amplitude and (2...3) times higher by frequency.

According to the requirements of the Russian Maritime Register of Shipping (RMR, 2008) SEE must operate reliably under the following environmental conditions: relative air humidity of 75±3 at a temperature +45±2°C; relative air humidity of 80±3% at a temperature of +40±2°C; relative air humidity 95±3% at a temperature of +25±2°C.

For ships of unlimited navigation area, the following nominal operating temperatures of the ambient air and cooling water are specified in engine and special electrical premises, galleys-from 0 to +40°C of air, +32°C of water; at open decks from -25 to +45°C of air in other premises from 0 to +40°C.

For ships intended for navigation outside the tropical zone, nominal operating temperatures of the ambient air and cooling water are respectively in engine and special electrical premises, galleys from 0 to +40°C of air +25°C of air at open decks from -25 to +40°C of air in other premises 0 to +40°C. Temperature up to 70°C should not cause damage to components, devices and systems.

SEE must remain operable under the following permissible deviations of electrical parameters: mains voltage (in % of the nominal value) from +6-10% at long-term deviations ±20% at short-term deviations within 1.5 sec mains frequency (in % of the nominal value) ±5% at long-term deviations and ±5% at short-term within 5.0 sec.

SEE must research reliably under the following mechanical effects: vibrations with frequencies from 2.0-80.0 Hz (at frequencies from 2.0-13.2 Hz with displacement amplitudes of ±1.0 mm and at frequencies from 13.2-80.0 Hz at acceleration of ±0.7 g at vibration sources (diesel and so on) or in the steering compartment at vibrations with frequencies of 2.0-100.0 Hz (at frequencies from 2.0-25.0 Hz with displacement amplitude of ±1.6 mm and at frequencies from 25.0-100.0 Hz at acceleration of ±4.0 g impacts with acceleration of up to ±5.0 g and frequencies between 40 and 80 beats per minute at long ship heels of up to 15.0 and pitch of up to 5.0 emergency Electric Drives (ED) at long-term heel of up to 22.5, pitch of up to 10.0 and at simultaneous roll and pitch in the above range at rolling of up to 22.5 with a period of (7-9) sec; at pitching of up to 10.0° vertically.

SEE is subject to the requirements for electromagnetic compatibility defined in the register. To assess the distortion of voltage curve of ship EPS, voltage curve unsinusoidality coefficient $K_u$ is widely used, defined as follows:

$$K_u = \frac{1}{U_c} \cdot \sqrt{\sum_{n=2}^{200} U_n^2} \cdot 100\,\% \qquad (1)$$

Where:
$U_c$ = Root-mean-square value of mains voltage
$U_n$ = The voltage of nth harmonic component (n is the sequence number of the highest harmonic component)
$K_u$ = Coefficient must not exceed 10%

For supply of high power sources of harmonic components of voltage in coordination with the Russian Maritime Register of Shipping, it is allowed to use certain bus types with $K_u$>10%, provided that these buses are connected to the mains through decoupling devices (rotary converters, special transformers, etc).

The main SEE include Electric Drives (ED) which are relatively complex technical products are intended for a certain period of operation and are maintainable. They consume up to 90% of electrical energy generated by ship generators (Sivers, 1975). According to RMR (2008), steering ED, Anchor and Mooring (AM) ED, bilge pumps, switchboards of ED of Lifting Mechanisms (LM) and others must be powered from the buses of the Main Switch Board (MSB) by separate feeders. If the ship is equipped with two and more mechanisms of the purpose similar to EP, except steering ED, compressors and pumps of sprinkler system, electric propulsion installation exciter sets, then at least one of these ED must be powered through a separate feeder from MSB.

In some cases, power from separate ED is commensurate with unit power of ship generators. Connecting of Electric Motors (EM) such as ED to the mains their operation and switching off is accompanied by voltage (and frequency) deviations in the ship network from the nominal values. In addition, EE of comparable power include the group of ED with non-linear elements in power networks (systems "frequency converter asynchronous EM", "thyristor voltage regulator asynchronous EM" and others).

Components (elements) of ED as technical objects have a certain sets of properties. One of main properties is reliability (Burkov, 2014). Complex methods actively used for assessing the impact of various factors on reliability of the products are the methods of analysis of variance (Kremer, 2009), allowing selecting generalized factors used to judge on the functional properties of ED.

The solution of problems of reliability of ship ED is conditioned by determination of nomenclature and appropriate values of reliability indices. In assessing the reliability indices of ship ED by the existing operating experience data, the peculiarities must be taken into account especially the following.

Due to the limited number of observed objects and relatively short periods of operational tests we have to deal with the aggregate of ships and consequently, consider the possibility of changes in the observed objects during the operation. Using operational and technical documentation and other sources of statistical materials for the majority of ship ED, we can find only the total number of failures for a certain period of time for the time period between failures.

Most of the components and elements of ship ED components are repaired or replaced in case of their failure. In case of failures of some components or elements thereof, serviceable components are sometimes replaced along with them. A number of ship ED components or elements can have failures both in operation and in non-operating state.

These peculiarities make it difficult to quantitatively assess reliability of the studied ship ED and prevent prescribe suggestion of methods. Recommendations for the normalized reliability indices of ship EO and Elements of Ship Automation (ESA) are given in Kuznetsov and Filev (1995) where a range of quantitative reliability indices include indices that best characterize the reliability of ship EE and ESA including ship ED and amenable to engineering analysis. The range of standardized reliability indices is determined depending on the class, time mode of operation, reliability group and the principle of use duration limitation.

The studied reversible adjustable ship ED with a high degree of reliability can be attributed to the third class (Kuznetsov and Filev, 1995) because the vast majority of them are repairable.

Time modes of operation of the adjustable ship ED defined by alternating transitions of stand-by and operation are different. If the main specific mode of operation of anchor and mooring ED is the mode close to S2, ED of LM work in the modes close to S3, S4, S5, S7 and S8 (Chilikin and Sandler, 1981). Thus, the specific time mode of operation of anchor and mooring ED is on-line mode and cyclical mode for adjustable ship ED of LM.

Depending on the consequences of failures, it is reasonable to refer the studied ship ED to a second group of reliability (Kuznetsov and Filev, 1995) based on the fact that the consequences of their failures that result in downtime of the ships can be: partial loss of the main functions of intended use of ships in particular in mooring, unmooring or berthing operations reduction in efficiency of handling operations. Duration of use of the adjustable ship ED seems forced as ED of these groups are decommissioned as a result of failures or reaching the ultimate states.

## RESULTS AND DISCUSSION

Reliability of the studied ship ED as repairable products is calculated based on the following considerations. Operation of good product begins at time t = 0. At the end of a random time period $t_i$ ED fails and within a random time $\tau_j$ measures are taken to restore its operating condition. This process continues until write-off of the product. Random variables $t_i$ and $\tau_j$ are independent (i = 1, 2, 3…k; j = 1, 2, 3…l; (k, l is the total number of operational conditions and failures of ED at the stage of consumption of the "life cycle", respectively). Operating experience of many electromechanical systems shows that the product stage of consumption is characterized by three major areas of $\lambda_0 = f(t)$ function, corresponding to: $\lambda_{01}(t)$-run-in operation ($0<t\leq t_1$); $\lambda_{02}(t)$ normal operation ($t_1<t\leq t_2$); $\lambda_{03}(t)$-wear and aging ($t>t_2$) (Kuznetsov and Filev, 1995).

In general, $\lambda_0 = f(t)$ function can be expressed by the use of Weibull distribution for probabilistic description of a random time to failure which is defined by two parameters: scale $\lambda_0$ and asymmetry of distribution k (Burkov, 2014). Where:

$$\lambda_o(t) = \lambda_o k t^{k-1} \tag{2}$$

ED failure probability density $f_0(t)$ and probability Q(t) of occurrence of the next failure is defined as:

$$f_o(t) = \lambda_{ot}^{k-1} e^{-\lambda_o t^k} \tag{3}$$

$$Q(t) = 1 - e^{-\lambda_? t^k} \tag{4}$$

And probability of ED failure-free operation R(t) is:

$$R(t) = 1 - Q(t) = e^{-\lambda_o t^k} \tag{5}$$

From (Eq. 3), ED failure probability density $f_0$ is defined as:

$$f_o(t) = \begin{cases} k\lambda_o t^{k-1} e^{-\lambda_o t^k}, \text{ at } t>0 \\ \text{at } t<0) \end{cases} \tag{6}$$

And probability R of failure-free operation from (Eq. 5):

$$R(t) = \int_0^t e^{-\lambda_o(t)} dt = e^{-\lambda_o t^k} \tag{7}$$

The dimensionless shape parameter k in Eq. 6 and 7 is determined by the results of experimental research.

## CONCLUSSION

According to boundedness of researches and performed research of reliability basic concepts in respect to marine electric motor drives having specific features, it was proposed to perform the analytic definitions based on Weibull distribution.

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