ESTIMATION OF UNAVAILABILITY OF MAIN POWER PLANT'S FUEL SUPPLY SYSTEM INSTALLED ONBOARD SEABED EXPLORING OFFSHORE VESSEL

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Summary

On the basis of observation of injectors failures in main diesel generators engines and failures occurred in whole marine fuel supply system, installed in engine room onboard multi support offshore vessel, selected reliability measures for this components has been estimated. Unreliability function and density probability of time to failure of injectors for calendar time and clean working time has been presented. Unavailability function for injectors and whole fuel supply system onboard analyzed vessel, calculated with use two different algorithms has been presented.

1. Introduction

Seas and oceans are bigger part of the surface of our planet and they are the environment of work for various special objects operated in offshore oil and gas industries for seabed exploring like oil rigs, drilling platforms, Floating Production, Storage and Offloading units and offshore construction multi support vessels, which are units worked for crude oil and natural gas exploration. Reliability of marine power plant systems and its components is very important point, because of the potential possibility to cause the environmental catastrophe in case of propulsion down, e.g. spill of oily products into the sea environment.

In the paper, the attempt at estimation of selected reliability measures for Detroit Diesel 149 engines injectors (fig. 1) on the background of marine fuel supply system, in which they are working. System is installed onboard offshore multi support vessel for constructing works in gas and oil exploration industries sector. Ship is dynamically positioned unit equipped with automatic DP system *Simrad ADP 703* type with backup *ADP 701* system. During DP operations vessel is utilizing for propulsion two aft azimuth thrusters *Ulstein TMC92* type (maximum constant power rate *1470 kW* each) end every of three bow thrusters *Ulstein 375 TV* type (maximum constant power rate 1100 kW each). Vessel is designed and operated according with third highest DP consequence class (*Consequence Class 3*). Very high level of structural, functional and distributed redundancy allows execution of the most difficult offshore construction jobs. [5, 6, 8].

Base for analysis has created by observation and registration of failures in offshore DP3 vessel's power plant unit systems in the years 2000-2003, i.e. over 37 months. Some of observed failures of injectors has been reason of diesel engine shut downs and connected with his unplanned maintenance works, and also some of failures has been discovered before down of engine. In analysis, time to repair has been treated as zero, from the point of view of their short repair time, in compare with time to down.

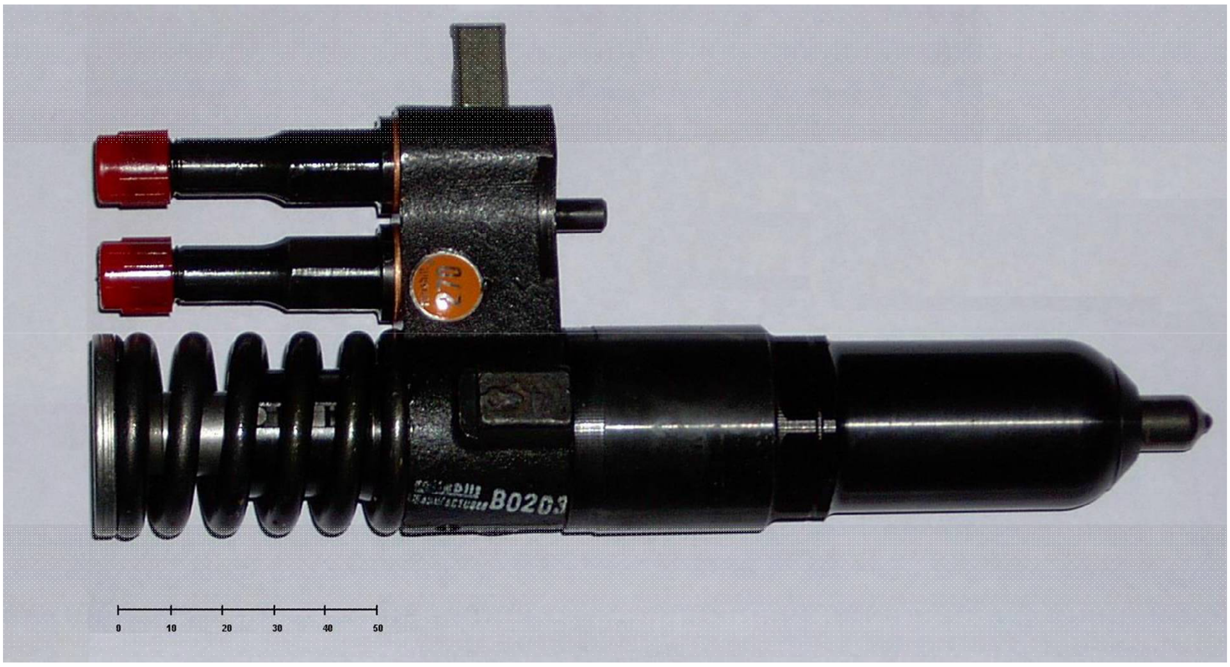

Fig. 1. View of Detroit Diesel 149 engine injector

2. Selected dependability measures of injectors

Based on observed moments of injectors failures, following measures has been estimated:

- mean time to failure:

$$\bar{t} = \frac{1}{n}\sum_{i=1}^{n} t_i = \frac{1}{14}\sum_{i=1}^{14} t_i \tag{1}$$

- variance of time to failure:

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(t_i - \bar{t})^2 = \frac{1}{13}\sum_{i=1}^{14}(t_i - \bar{t})^2 \tag{2}$$

- standard deviation of time to failure:

$$s = \sqrt{s^2} \tag{3}$$

- lower quartile of time to failure (value of time to which 25% of population will be down);
- median of time to failure (value of time to which 50% of population will be down);
- upper quartile of time to failure (value of time to which 75% of population will be down);
- coefficient of variation, which measures the spread of a set of data as a proportion to its mean value.

$$\square = \frac{s}{\bar{t}} \tag{4}$$

- mean deviation, which measures mean of the absolute deviations of a set of data about the data's mean (bounded values sensitive of this measure is lower then for standard deviation):

$$d_1 = \frac{1}{n}\sum_{i=1}^{n}\left|t_i - \bar{t}\right| = \frac{1}{14}\sum_{i=1}^{14}\left|t_i - \bar{t}\right| \tag{5}$$

Estimated measures has been presented in table 1, for calendar time as well as so called clean time of engines work (real working time).

Table 1. Estimated dependability measures of injectors created for calendar and working time of operation

Basic measure		Time	
		calendar	real work
mean value	[h]	8657	4872
variance	[h^2]	58385524	19774657
standard deviation	[h]	7641	4446
lower quartile	[h]	1734	1056
median	[h]	7680	3690
upper quartile	[h]	12600	8010
coefficient of variation	[-]	0,88	0,91
mean deviation	[h]	5962	3595

On the basis on estimated mean value of time to failure, failure intensity function has been calculated. Intensity function values has presented In table 2. According to [7, 10] time to failure distribution Has assumed as exponentional distribution.

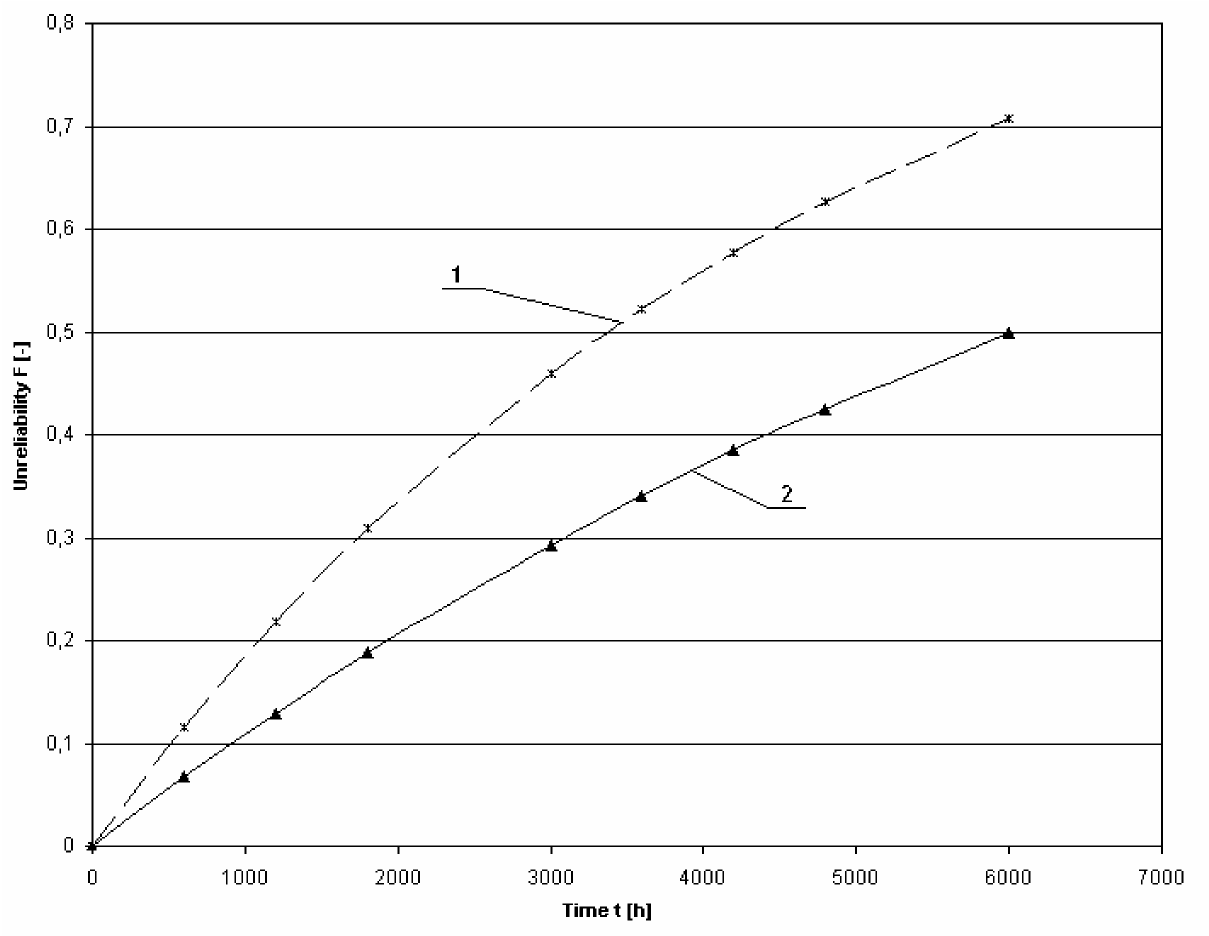

Fig. 2. Estimated unreliability function *F(t)* of injectors: 1- real working time; 2 – calendar time

Table 2. Estimated failure intensity function values

Failure intensity		Time	
		calendar	real work
$\lambda(t)$	[h^{-1}]	$1,16 \cdot 10^{-04}$	$2,05 \cdot 10^{-04}$

For given intensity function values graphs of probability distribution function (unreliability function) of injectors *F(t)* and probability density of time to failure function *f(t)* has been presented bellow on fig. 2 and 3.

We assume that injectors are working to failure moment, in other words injectors are treated as non-repairable elements. This assumption allow treating unavailability function as equal probability distribution of time to failure function. On the figure 4, comparison of unavailability function diagrams for injectors and whole system (for two different operation states) with use of ERAC algorithm [2, 4] has been presented.

Fault tree which can be reliability model of analysed system, have n independent input events. Let $y = (y_1, y_2, \ldots y_n)$ denote the random state vector of the input events, where y_i is equal to 1 when i-th input event occurs and 0 otherwise. Now, let A denote all the states y of the fault tree such that the top event occurs.

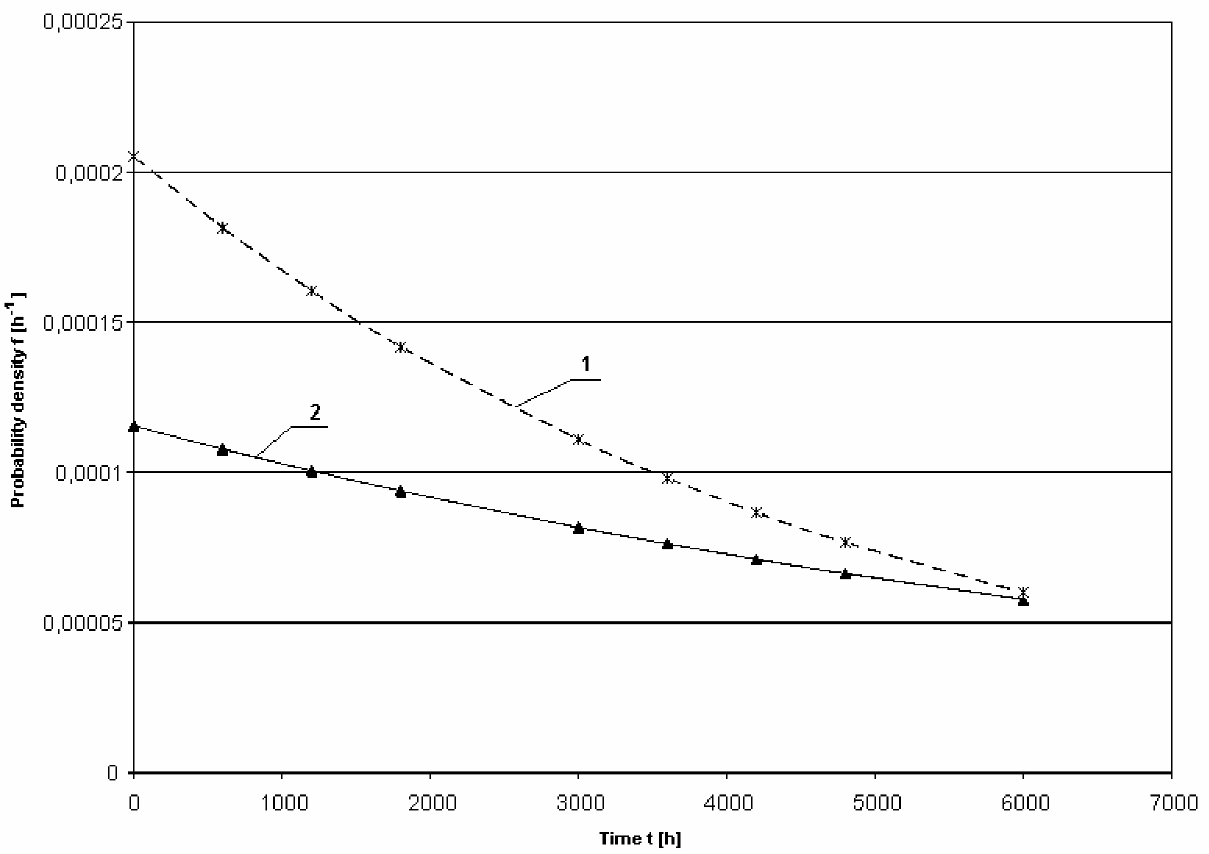

Fig. 3. Estimated probability density function *f(t)* of injectors: 1- real working time; 2 – calendar time

The probability $Q_0(t)$ of the top event is thus determined by:

$$Q_o(t) = \sum_{\bar{y} \in A} P[\bar{Y}(t) = \bar{y}] \quad (6)$$

If assume, that:

$P[Y_i(t) = 1] = q_i(t)$

$P[Y_i(t) = 0] = 1\text{-}q_i(t) = p_i(t)$

then probability, that system is in state given by vector y from set A is given by:

$$P[\bar{Y}(t) = \bar{y}] = \prod_{i=1}^{n} p_i(t)^{1-y_i} q_i(t)^{y_i} \quad (7)$$

Each of forward engine rooms has its own fuel supply installation. Two engine room fuel mains may be cross-connected by opening two valves, one on each side of the bulkhead between the engine rooms. States of operation of fuel system presented on figures 4 and 5 are connected with different positions of crossover valves, i.e. opened (engine rooms connected) and closed (engine rooms divided). For this states analyzed system has different reliability and functional structure, what is connected with different cooperated elements configurations. Prior to DP Class 3 operations, procedures using checklists will ensure that all crossover valves are closed. It can give partly success of system performances in case of black out in one of main engine rooms. All procedures cooperation of engine rooms during DP operations are performed according to IMCA (The International Marine Contractors Association) requirements [6].

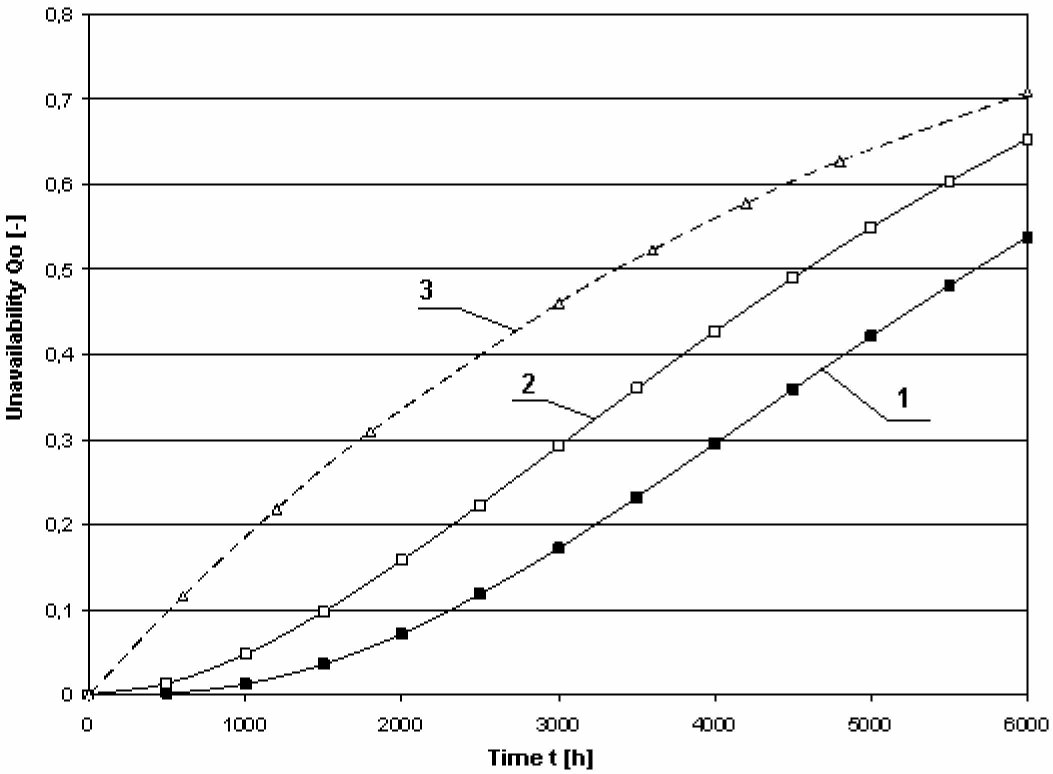

Fig. 4. Estimated unavailability *Qo(t)* of injectors and whole system calculated with use of ERAC algorithm: 1 – fuel system – the engine rooms connected; 2– fuel system – the engine rooms divided; 3 – injectors

Similarly, on figure 5 comparison of unavailability function diagrams for injectors and whole system (for two different operation states) with use of fast upper bound approximation (UBA) method [1, 2] has been presented.

We assume that the system unavailability $Q_0(t)$ can be approximated as the ip-function of the minimal cut sets unavailabilities $Q_k(t)$. All minimal cut sets of the fault tree are denoted as $C_1, C_2, \ldots C_n$. By the assumption of independence of input events, the probability that all input events in the minimal cut set C_k occur, is given by formula (8).

$$\breve{Q}_k(t) = \prod_{i \in C_K} q_i(t) \tag{8}$$

If the cut sets were disjoint, then they would be stochastically independent and we have:

$$\breve{Q}_o(t) = \breve{Q}_{0UBA}(t) = \coprod_{k=1}^{n} \breve{Q}_k(t) = 1 - \prod_{k=1}^{n} [1 - \breve{Q}_k(t)] \tag{9}$$

In general, however, the minimal cut sets for marine systems are not disjoint. In this case we always have:

$$Q_o(t) \le 1 - \prod_{k=1}^{n} [1 - \breve{Q}_k(t)] \tag{10}$$

In fact $Q_0(t)$ approximately equals the right hand side of (10), at least when the $q_i(t)$'s are close to 0. It should be noted that the inequality (10) can be also applicable when the input events in the fault tree are positively dependent (so-called associated) rather than independent.

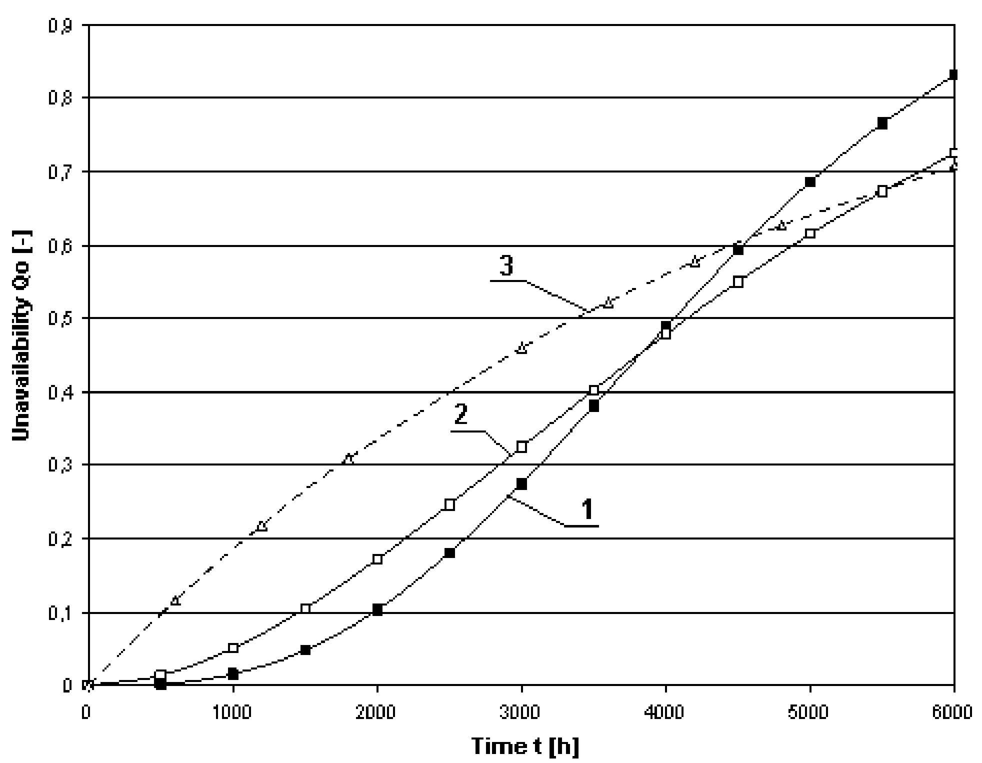

Fig. 5. Estimated unavailability *Qo(t)* of injectors and whole system calculated with use of UBA method: 1 – fuel system – the engine rooms connected; 2– fuel system – the engine rooms divided; 3 – injectors.

3. Final conclusions

For estimate of reliability measures in reference to real working time given engines, introduction of time scale coefficients has been proposed. Coefficients has calculated for three years time of observation on the basis of working time counters as proportion clean (real) working time to calendar time. Calculations these for five main generators (MG 1 ÷ MG 5) has presented in table 3, where are given: beginning and ending date and respective hours counters for start and stop of observation, and finally proportion of these times i.e. time scale coefficients.

Based on presented unavailability functions values, we can observe value that unavailability of injectors is between estimators of unavailability of whole fuel supply system obtained with use of ERAC and UBA algorithms, for time over 5000 hours. Before this time, unavailability of injectors is higher then measures for system.

Table 3. Estimation of time scale coefficients for main generators

Engine	MG 1	MG 2	MG 3	MG 4	MG 5
Beginning date	01-01-00	01-01-00	01-01-00	01-01-00	01-01-00
Ending date	01-01-03	01-01-03	01-01-03	01-01-03	01-01-03
Beginning hours counter	23085	17018	26630	24378	20644
Ending hours counter	37251	31084	42051	40857	32722
Calendar period [days]	1080	1080	1080	1080	1080
(Ok) Calendar period [h]	25920	25920	25920	25920	25920
(Or) working time [h]	14166	14066	15421	16479	12078
Coefficient (Or / Ok)	0,54652778	0,54266975	0,59494599	0,63576389	0,46597222

Therefore, there is possibility to utilize reliability measures of the most numerous component for preliminary estimation of whole system characteristics. Estimation this is based on factor given number of presence of *i*-th event [3, 9] in modeled system fault tree (this element is member of more number of minimal cut sets of system). In this case as component this are injectors.

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SZACOWANIE NIEGOTOWOŚCI SYSTEMU ZASILANIA PALIWEM SIŁOWNI OKRĘTOWEJ STATKU WSPOMAGAJĄCEGO EKSPLORACJĘ DNA MORSKIEGO

Na podstawie obserwacji uszkodzeń pompowtryskiwaczy silników spalinowych zespołów prądotwórczych i systemu zasilania paliwem siłowni okrętowej statku wspomagającego eksplorację dna morskiego oszacowano wybrane charakterystyki niezawodnościowe. Dokonano porównania przebiegów oszacowanych funkcji niezawodności i funkcji gęstości rozkładu uszkodzeń pompowtryskiwaczy dla czasu kalendarzowego i czasu pracy silników. Porównano przebiegi niegotowości pompowtryskiwaczy i systemu paliwowego analizowanego statku oszacowanego dwoma różnymi algorytmami analitycznymi