

# DIAGNOSIS OF THE TECHNICAL CONDITION OF A MARINE POWER PLANT

## DIAGNOZOWANIE STANU TECHNICZNEGO SYSTEMU SIŁOWNI OKRĘTOWE

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### Summary:

Problems related to the diagnosis of the marine power plant technical condition have been presented. Basic cause-and-effect relationships among power plant sub-systems have been shown. Applying the concept of system unavailability has been suggested as a method which may be found useful in the estimation of ship's engine room technical state. The fuel system feeding the main engine of one of B-584 series vessels has been used to carry out a quality and quantity analysis of measurement points and to consider a possibility of practical application of selected diagnostic tests and processes of the system unavailability to serve as an aid in identifying failures. Changes in locating monitoring and measuring points in the system have been proposed thanks to which a more detailed assessment of its technical condition could be possible.

### Anotace:

Na przykładzie złożonego systemu technicznego jaki stanowi siłownia okrętowa przedstawiono problematykę oceny stanu technicznego oraz lokalizacji uszkodzeń w podsystemach siłowni z wykorzystaniem metod stosowanych w eksploatacji tych obiektów. Przedstawiono topologiczny model siłowni przedstawiający zależności między podsystemami. Pokazano możliwe najczęściej występujące stany niezdatności dla wybranego systemu siłowni okrętowej. Przedstawiono przebiegi niegotowości systemu w celu wizualizacji procesu pogarszania się stanu technicznego. Zaprezentowano uwagi dotyczące metod oceny stanu technicznego systemów siłowni okrętowej.

### 1. Introduction

The reliability of a marine power plant, including its systems and functional elements is one of the fundamental features to be considered in ensuring that a vessel in operation will satisfy its ultimate goal of carrying people and cargo. An analysis of the technical condition of machines and devices in the engine room allows identifying the most unreliable parts and implies the use of a variety of methods which will aim at reducing failure rate. Although the reliability of technical items enables finding the so called „weak links” and various parameters that are characteristic of a given technical item from the reliability viewpoint, the achievement of satisfactory results may only be based on long term testing of models or real objects. Therefore, in spite of the fact that the inference resulting from reliability tests has a huge impact on designing changes of future and

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present day technical items, the methodology of these tests does not meet the requirements which are imposed on the running evaluation of the technical condition of complex technical items. It follows that surveillance and control of technical systems should rely on diagnostic methods.

The marine power plant is a highly complex structure composed of numerous systems, sub-systems and functional elements. Proper operation of that technical item depends largely on the knowledge and skills of the maintenance staff and on the kind of design solutions applied, the structure of components and their operating conditions.

The integral operation of ship's engine room consists of current monitoring, maintenance and adjustments of operational conditions and components of the marine power plant; planned and unplanned overhauls and repairs; diagnosis of all faults and malfunctions in the work of technical items; predicting future states.

Electronic systems of measurement, monitoring and control have become widespread solutions: systems offered by Siemens, Norcontrol and Lingsoe are good examples. Fault finding systems are also being developed, with less impact however than the former ones, due to high financial costs. Computer aided systems of overhaul planning, recording, creating technical specification and store managing as well as ordering spare parts are also developed. Prediction systems of operational states belong to the least developed ones.

## **2. The purpose and scope of marine power plant diagnosis systems**

Constant efforts to make progress in the automation of surveillance and diagnosis of ship's engine room and navigational aids are an effect of changing over to unmanned watches in the engine room; considerable losses connected with the ship being incapable of sailing, high costs of repairs or long lay-days of the ship due to improper timing of repairs and their scope as well as considerable discrepancies between pre-planned and actual repair specifications; attempts to provide the utmost safety of ship's crew and cargo as well as the environment.

Thanks to modern technological developments (computers, microprocessors, information technology, etc.) „intelligent” surveillance and diagnosis systems are increasingly used on board ships[1]. The systems in question perform the following important functions: measurements of changes in characteristics of the processes under surveillance (technical items) and calculating relevant measures; calculating standardized parameters (indicated power, propeller shaft horse-power, specific fuel consumption, etc.), alarm of exceeding limit values which can be determined or calculated according to the operational conditions of a given device (e.g., energetic fluids parameters of a diesel engine); calculating and analyzing the tendency of engine state parameters ( i.e., analysis of the trend in working parameters changes); predicting the condition of a technical device (development of an improper operating condition) based on the mathematical heat model of the device and current measurement of selected relevant quantities; long term prediction of the technical device condition on the basis of its diagnosis mathematical model and the calculated measures of the analyzed physical quantities. The diagnostic model is designed on the basis of device parameters analysis in a long run and failure rate statistics; automatic determination of fault causes and recording the data pertaining to a fault (recording on a hard disk and a printer); transmitting and segregating data related to the time the device was repaired or its part replaced (e.g., turbocharger bearings, repairs of air compressors, overhauls of crank-piston arrangements, etc.); possibility of interaction with satellite communication systems (surveillance and consulting aid from the owner's

experts); automation of switching on/off devices in various working stages (failure, load increase, etc.)

Nowadays, among best known marine power plant surveillance systems for single devices or their components used in the engine room, the following should be mentioned: COMOS, MACAS and MICOS of the Mitsubishi company, CYLET MIP of the ABB company, DATA CHIEF of the Norcontrol company, System of the MSN company, etc.

### 3. An example of selected diagnostic tests used for fault location in the fuel system.

Whether the evaluation of the technical condition of a given system is possible or not will depend on the number of available parameters describing that system. Those parameters are obtained from sensors and can be utilized in the diagnostic inference process for describing the system. The analysis was carried out using the main engine fuel supply system (Fig.1) of a B-584 series vessel [2], in which observations were performed while the marine power plant was in operation at sea.

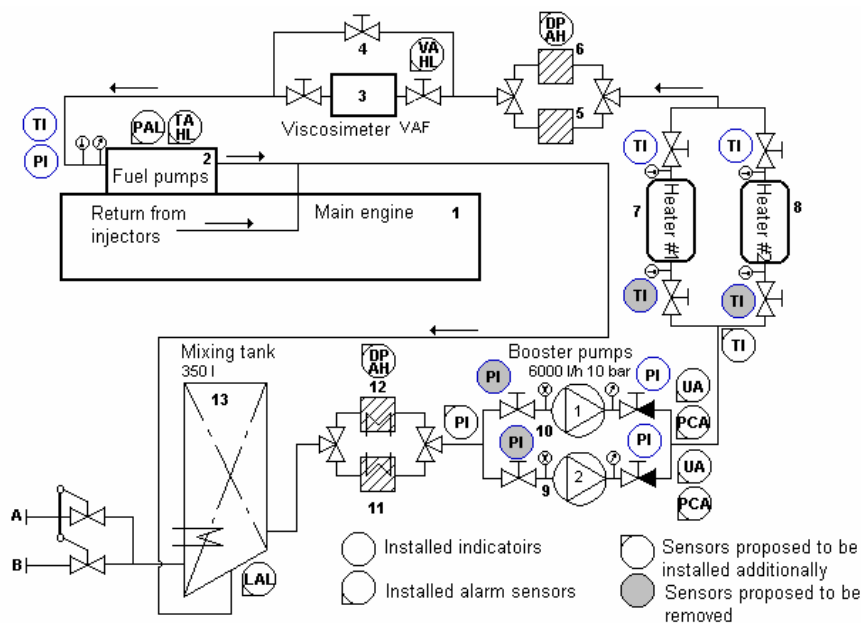


Fig. 1 A simplified diagram of main engine fuel supply system.

The analysis took into consideration the following components of the system: mixing tank (13), strainers (11, 12), booster pumps (9, 10), steam heaters (7, 8), fine filters (5, 6), viscometer (3), injection pumps (2), and main engine (1). The engine can be fed with both Marine Diesel Oil and Heavy Fuel Oil, the kind of fuel depending on the position (A, B) of the control shut-off valves which are fitted between appropriate service tanks and the mixing tank. Fuel is sucked by one of the supply pumps from the mixing tank through one of the strainers and discharged into one of the heaters, one of the fine filters, and next into the parallel viscometer unit as well as the by-pass valve (4) to be finally sucked by injection pumps feeding the main engine. The fuel from overflows of the injection pumps and the injectors returns to the mixing tank. Alarm sensors and measurement sensors have also been shown in the diagram. New sensors to be added have been suggested, whereas those regarded as excessive have been eliminated.

The following symbols of the measurement and control instruments have been used: PI – pressure indicator, TI – temperature indicator, DPAH – alarm of high difference

in pressure on the filters, LAL – alarm of low level of fuel in the tank, PAL – alarm of low level of fuel pressure before the engine, PCA – low pressure alarm- start pumps, UA – pump blocking alarm, VAHL – fuel high and low viscosity alarm, TAHL – alarm of low and high fuel temperature before the engine.

Information about the condition of an item can be obtained by means of trials. Performance of each of the trials can divide the set  $E=\{e_1, e_2, \dots, e_z\}$  into two subsets. The first subset can be said to contain or not to contain faulty elements (respectively, a positive or negative result of the testing), and the second subset, about which the same can not be said. The set of trials  $T_d \subset \Pi$  which enables to distinguish all possible  $W$  states, in which an object of the diagnosis can be found is called a diagnostic test. There are various types of diagnostic tests such as: one-by-one testing, Boolean matrix method, information method, group control method, half-half split method, optimization methods, etc.

To simplify the analysis, a functional structure of the fluid flow in the main engine fuel supply system has been designed and shown as a graph (Fig. 2).

In relation to the described system a performance test and a fault locating test have been set up using the Boolean matrix method and a diagnostic graphical model has been designed for the one-by-one testing [2], which have not been mentioned here due to the volume of material. In the analysis, those elements have been accounted for which are most relevant from the point of view of full functionality of the system.

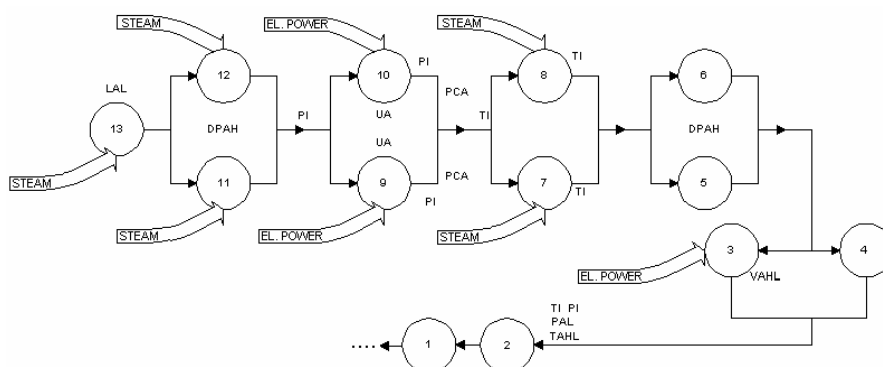


Fig. 2. Functional structure of the main engine fuel supply system.

Taking into account the fact that the engine room of the examined ship was not automated, it possessed only the most essential measuring instruments which, by and large, consisted of the instruments for a direct read-out (thermometers, manometers, and manovacuumeters). The symbols indicating the elements of the fuel system as well as monitoring and measurement points have been kept identical as those given in the system layout (Fig.1)

The function of unavailability  $Q(t)$  may serve as the measure denoting the exhaustion of the system capability used for calculating the probability that at the instant  $t$  the system will not be able to perform the tasks it is designed for. Figure 3 shows the runs of the function for the operation in normal conditions,  $FNA$  and  $FNN$  for the conditions when one of the filters in the fuel system has been clogged. The analyses were carried out while using two methods, i.e.  $UBA$  (unavailability border approximation) and  $ERAC$  (exact reliability and availability calculation) [4]. As it results from the graph shown, the system demonstrates high sensitivity to filter foulness. Models like those can be used for technical condition assessment to evaluate particular parameters in the respective instants of the operating time [3].

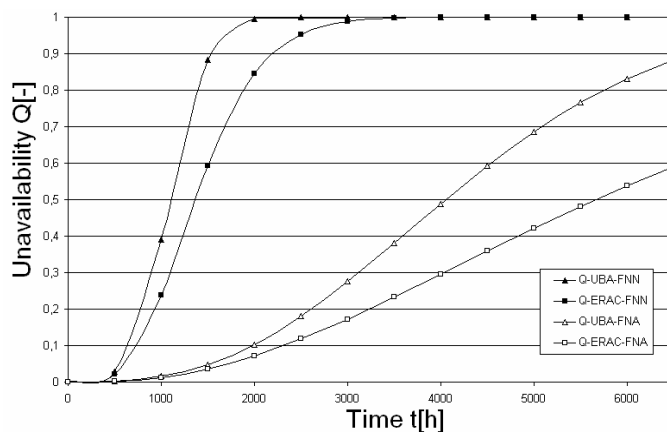


Fig. 3. Influence of a specific fault of an element on the system unavailability

#### 4. Final conclusion

Rational solutions should be pursued to afford a description of the state of a system with high accuracy while taking great care to keep the costs connected with the implementation and maintenance of diagnostic systems at the lowest possible level.

The analysis herein presented helped to find such a solution in terms of a rational number of measurement points fitted in the system. It is known that while increasing the number of sensors it is possible to determine the state of a given item with an increasingly greater accuracy. However, this increases the costs of system operation. Therefore, redundancy of measurement instruments should be avoided. The implementation of the methods described in the diagnostic process of the system requires an appropriate mathematical model to be designed which will allow describing all possible conditions in which a given technical system can be found.

It should be borne in mind, however, that even the best mathematical diagnostic model will prove useless if we do not know the values of an adequate number of parameters describing the state of the system and its components. On the basis of a thorough analysis of the main engine fuel supply system it has been found out that the number of measurement points is not sufficient to describe all the possible states accurately, whereas the number of some measurement instruments is higher than required.

To increase the effectiveness of the diagnosis process the following changes in sensor arrangement in the described system have been set forth: to improve the degree of successful diagnosis of the functioning of the system and enhancing its dependability it is necessary to install in the system, two additional pressure difference sensors on fuel filters; to decrease the cost of installation it has been proposed to eliminate two pressure gauges (manovacuumeters) at the suction end of the fuel supply pumps, at the expense of fitting one manovacuumeter on the common suction collecting pipe for both pumps; to reduce the cost of installation it has been proposed that two temperature sensors (thermometers) on the inflow to the steam heaters be eliminated, at the expense of fitting one thermometer on the joint feeding manifold.

Complexity and unpredictability of operational conditions in which a given system may have to work, and high costs of repairs that can not be accounted for call for further

studies in the field of diagnostic methods, and methods of safe and effective running of ship installations, including the adaptation of reliability measures (e.g., the one which has been used here: system unavailability) in designing diagnostic models.

A very high complexity of technical items necessitate the use of computers as an aid to control data flow from the sensors of monitoring and controlling systems, and to the actuators of the control and protection units. Another question that arises is the uncertainty of knowledge, for example in the diagnosis of complex items with highly changeable operating characteristics.

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