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Measurements of exploitation and diagnostic parameters of ship power system

SUMMARY

The role and importance of exploitation and diagnostic measurements for safe and effective operation of ship power systems were discussed. Characteristics of the measurements were shortly presented. Basic apparatuses, measuring and monitoring systems for carrying out of the measurements were described. Present developments in the area were pointed out and characterized.

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INTRODUCTION

The modern ship considered as a controlled plant consists of three main systems:

- navigation system (N)
- power system (PE)
- cargo system (C)

each of them includes some subsystems, respectively (see Fig.1):

- operation subsystem (O)
- course stabilization subsystem (CS)
- propulsion subsystem (P)
- steam subsystem (S)
- electric power subsystem (EPE)
- air conditioning and cooling subsystem (ACC)
- cargo handling subsystem (CH).

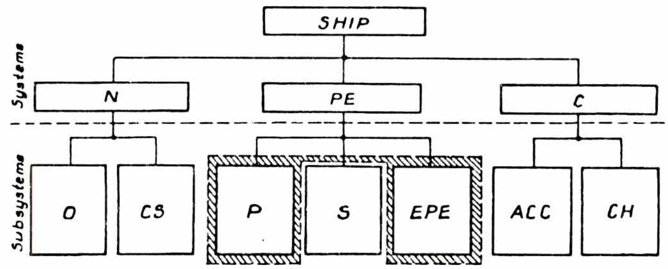

Fig.1. Functional block diagram of an automated ship (notation in above given)

Among the subsystems shown in Fig.1 the electric power subsystem, an important element of the ship power system, and that decisive of the correct and reliable operation of the navigation and cargo systems, is of fundamental importance for safety and effective operation of the entire ship. The electric power subsystem is very closely related to the propulsion one, especially on the ships where electric energy is produced also by main-engine driven shaft generators or turbogenerators supplied with main engine exhaust gas energy [2, 3, 4].

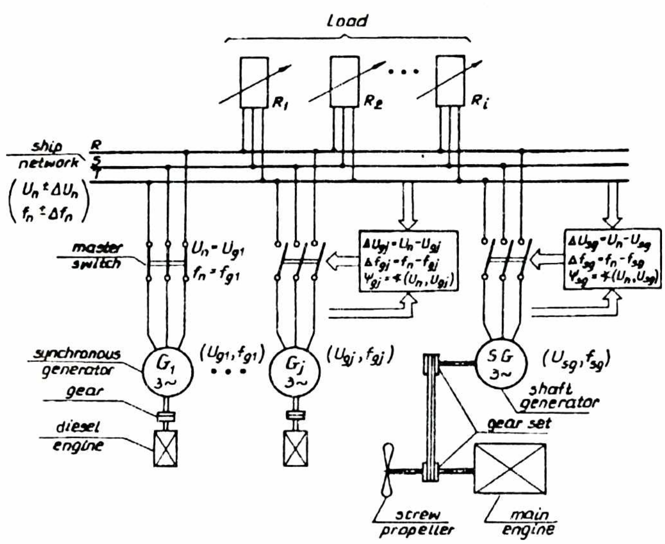

Fig.2. Ship power system with shaft generator and diesel engine driven generating sets: G_1 - pilot generator, G_i, SG - synchronized generators, R_i - energy receivers

The ship power system consists of the plants for producing the electric energy, Fig.2. The system can be considered as a difficult and hostile environment for carrying out the measurements because of its changeability and many disturbing factors, e.g. mechanical vibrations, shocks, electromagnetic fields and essential changes of atmospheric parameters. The ship power system is usually treated as a flexible network because of significant changes of electric frequency and voltage. The voltage changes, ΔU_n, can reach even ±20% of the nominal value of network voltage and the simultaneous fluctuation of frequency, Δf_n, not exceed ±10% of the nominal value of network frequency [2,5]. The conditions result of the fact that the power of switched-on energy receivers, e.g. bow thrusters, is comparable with that of the ship electric power system. Moreover, power semiconductors used very often in shipboard drive systems distort current and voltage waves in ship network [6,7].Therefore the parameters of the system should be under permanent control by carrying out the exploitation and diagnostic measurements.

REMARKS ON SHIP ELECTRIC POWER STATION CONTROL AND MEASUREMENTS

Basic functions realized by the ship electric power system are: production, distribution and usage of electric energy. The most important control processes connected with functioning the ship electric power station are:

- preparing and starting the generating sets
- synchronization of a generator with the electric network or another generator
- cooperation of the shaft generator with the ship electric network
- frequency control and active power distribution
- voltage control and reactive power distribution
- ship electric network load control.

Technical realization of the operations requires measuring such quantities as: current (I), voltage (U), frequency (f), active power (P), reactive power (Q).

Moreover to control it is necessary to continuously measure non-electric quantities such as temperature, pressure, flow, level, rotations and others. The basic aim of the exploitation and diagnostic measurements finally is to ensure conditions for the safe and effective functioning of the electric power system and, possibly, utilization of full resource periods of particular devices at the minimum damage probability [8].

EXPLOITATION MEASUREMENTS

The aim of the exploitation measurements of the electric power system is to determine current values of important parameters of the system and control correctness of its work and processes connected with it. The parameters concern electric quantities of the electric energy as well as non-electric quantities of the devices responsible for safe and reliable operation of the ship electric power station. For example, exploitation measurements dealing with generating sets operation are:

- operation parameters of generator driving device and other characteristic parameters such as fuel quality, exhaust gas quality etc.
- electric energy parameters (mainly voltage and frequency)
- generator load parameters expressed by values of absorbed currents and power (with phase shift accounted for)
- parameters decisive of operation conditions of generating sets, expressed mainly by temperature, pressure and flow measured in characteristic point of the systems under consideration.

The following can be determined while taking into consideration a way of control (monitoring) of exploitation parameters:

- parameters with the range control realized by range sensors of both parametric and generating types
- parameters with the extreme control („min and/or max") realized by extreme control sensors.

Sometimes a combination of the above mentioned ways of control is applied. In this case range-extreme control sensors can be used which are range sensors with simultaneous extreme exceedance control realized mechanically or electronically by means of appropriate comparative procedures.

Exploitation measurements of the electric power system are performed by using:

- board instruments installed in the main and emergency switchboards
- measuring converters of electric and non-electric quantities, with normalized voltage or current output signal, installed in automatic control loops
- autonomous control-signalling systems
- integrated control-signalling systems.

The control-measuring apparatus installed in the main switchboard is destined for manual control and current supervision of the engine control room. The generator field of the exemplary apparatus of an one-generator system, shown in Fig.3, is equipped with instruments to measure values of active and reactive power, current, frequency and voltage of the generator and ship networks, generator real work time meter, and also with synchronizing and control apparatuses connected with the generator.

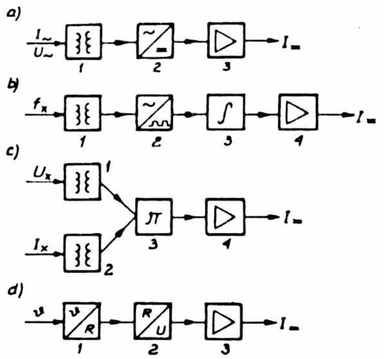

Fig.3. Exemplary block diagrams of the measuring converters for converting the electric and non-electric quantities into normalized direct current signal

a) Alternating voltage or current converter: 1 - transformer, 2 - rectifier, 3 - amplifier
b) Frequency converter: 1 - transformer, 2 - converting element of sinusoidal wave into rectangular signal, 3 - integrator, 4 - amplifier
c) Active power converter: 1 and 2 - transformers, 3 - multiplier, 4 - amplifier
d) Temperature converter: 1 - resistive thermometer, 2 - unbalanced Wheatstone bridge, 3 - amplifier

Another example of the exploitation measurements in the electric power systems is the application of converters of both electric and non-electric quantities to automatic control [9,10]. Some schematic diagrams of measuring converters applicable to automatic control systems of ship electric power station are shown in Fig.4.

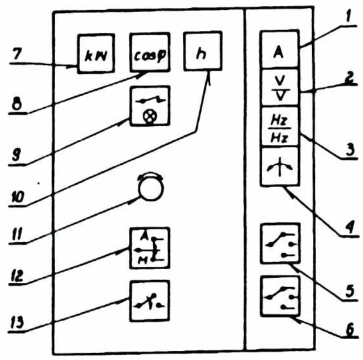

Fig.4. Control - measuring apparatuses of the main switchboard - exemplary equipment for one generator: 1 - generator current measuring device, 2 - generator or network voltage measuring device, 3 - generator or network frequency measuring device, 4 - phase accordance detector, 5 - current measuring commutator, 6 - voltage measuring commutator, 7 - generator active power measuring device, 8 - power factor measuring device, 9 - generator windings preheating device, 10 - generator work time meter, 11 - frequency regulator, 12 - switch-on (A - automatic, M - manual position), 13 - manual switch-on button

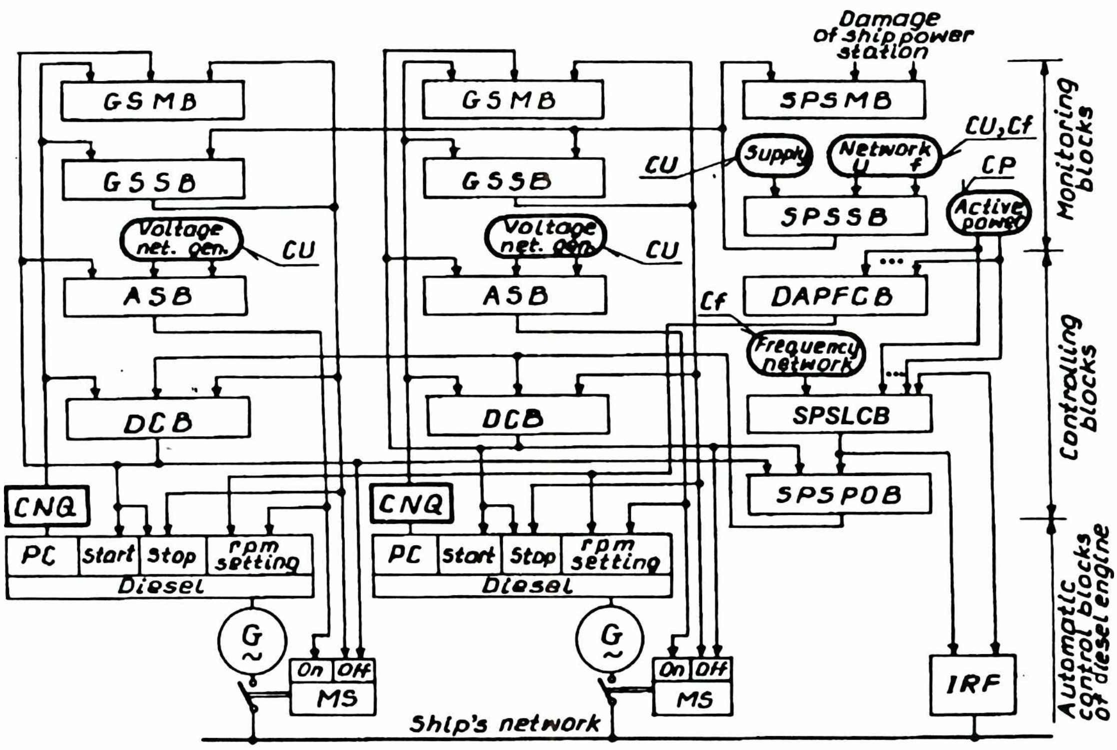

Fig.5. Exemplary block diagram of a ship power station's automatic control system
GSMB - generating set monitoring block; SPSMB - ship power station monitoring block; GSSB - generator set safety block; CP, CU, Cf - electric quantity- to-normalized DC signal converters of power, voltage and frequency, respectively; SPSSB - ship power station safety block; ASB - automatic synchronizer block; DAPFCB - active power distribution and frequency control block; DCB - diesel engine control block; SPSLCB - ship power station load control block; CNQ - non-electric quantity converters; SPSPOB - ship power station programming operation block; PC - control of parameters; MS - master switch; IRF - important receivers field

All presented solutions are of an almost linear relationship between the current output signal and measured quantity. Usually, a galvanic separation between the controlled network or device and the output signal is required. The converters are installed in automatic control loops to cooperate with respective control blocks of diesel engines, and control and monitoring blocks of the ship electric power station (Fig.5) [2].

Separate groups of instruments intended for the exploitation measurements (often also for diagnostic measurements) are the autonomous and integrated control-signalling (monitoring) systems. An illustration of the autonomous system can be the multi-point remote temperature measurement system of the AUTRONICA [11], presented in Fig.6, with optional, changeable parametric sensors:

- Pt100 thermoresistors of the range of 0 to 160°C
- T500 thermistors of the range of -40 to 60°C
- T802 thermistors of the range of 0 to 100°C,

or generating sensors:

- NiCr-Ni thermocouples of the range of 100 to 500°C.

Choice of the sensors depends on a type of the object to be controlled (main engine, generating sets, auxilliary devices), required measurement accuracy and conditions. Nowadays the integrated monitoring systems equipped with microprocessors and computers are mostly used. An example of such system can be SIMOS 31 integrated monitoring system (Fig.7) often installed in the ship engine control rooms [11].

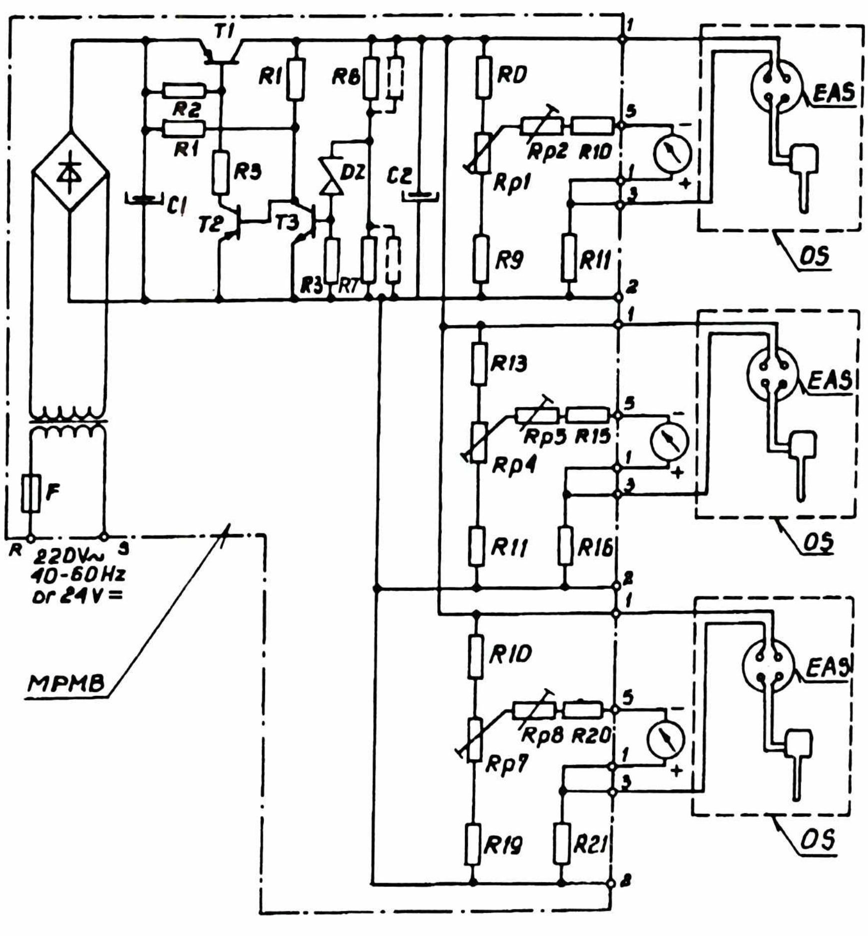

Fig.6. Exemplary multipoint temperature remote measurement system of AUTRONICA [11]
EAS - electronic adjusting system, MPMB - multipoint measuring bridge, OS - optional sensors

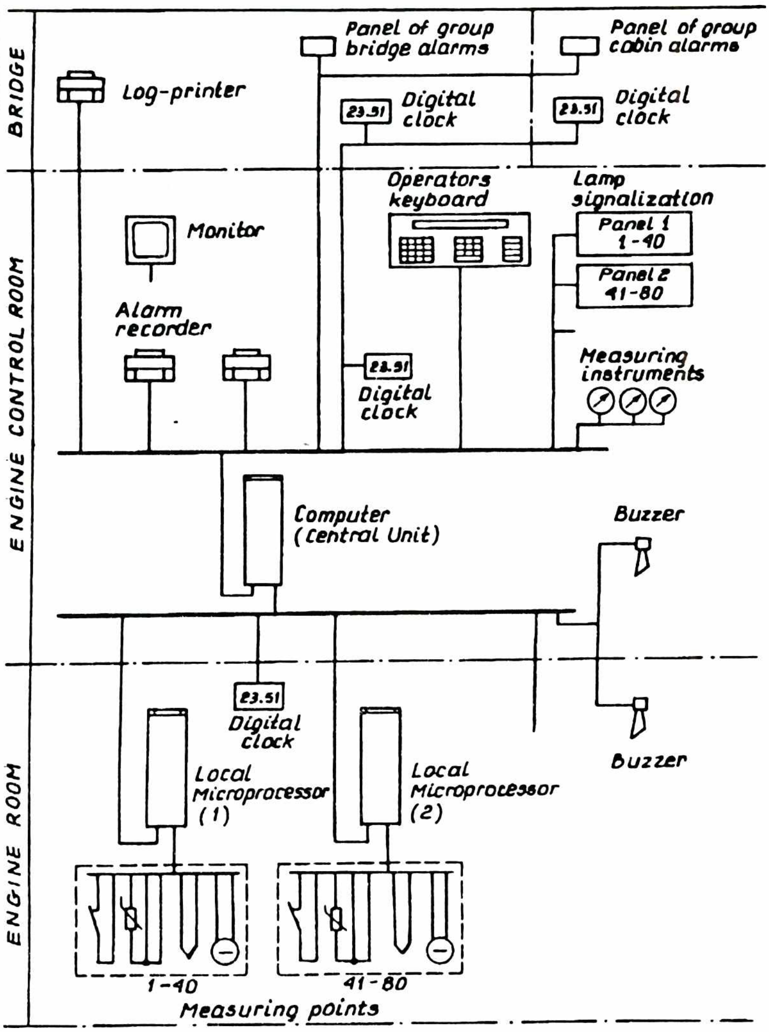

Fig.7. SIMOS 31 integrated monitoring system of SIEMENS [11]

The SIMOS 31 system (or similar) usually fulfils the following functions:

- periodic measurements of instantaneous values of controlled exploitation parameters of different system's elements
- current visualization of the measurement results
- monitoring and recording the extreme value exceedance of controlled parameters.

The SIMOS 31 is a parallel-series-parallel system [8] suitable to cooperate with four kinds of input elements, i.e. binary-extreme sensors, parametric and generating range sensors and also measuring converters with the normalized output current signal of 4 to 20 mA. The sensors are joined into groups of 40 pieces each. A number of the groups is dependent on the control needs. Each group is equipped with a local microprocessor intended for the processing of measuring signals. All groups are connected to the central computer where final measurement results are elaborated and directed to output indicators, inclusive of light and sound alarms, alarm recorder, log printer, monitor etc. Introduction of the integrated monitoring systems did not eliminate the autonomous systems and main, auxiliary or local control desks. The redundancy measurements of many important parameters are very often used beacuse of the high safety requirements for ship exploitation systems.

DIAGNOSTIC MEASUREMENTS

Diagnostic measurements of the ship electric system mainly concern the power plants (generator drive diesel engines and main engine) and ship power network. An aim of the diagnostic measurements depends on a technical state of the devices. Diagnostic measurements of the working electric power system (or its elements) permit to determine optimum conditions of the system and are complementary to the exploitation measurements. On the other hand, the diagnostic measurements which concern damaged plants are mainly of repair and preventive character.

For this reason the aim of the diagnostic measurements of the working electric power system is:

- to measure average values of selected parameters and predict their changes
- to monitor and record exceedance events of extreme values of the controlled parameters
- to diagnose state of wear of system's elements and forecast a time instant for their removal and repair.

Quite a different character is of the diagnostic measurements carried out on damaged objects. Their basic aim is to reduce the time necesary for detecting place and nature of a damage and its consequences to the object and its surrounding.

The diagnostic measurements of the electric power systems may be executed by means of:

- stationary diagnostic devices
- portable diagnostic devices
- computer-aided diagnostic devices
- testers.

The stationary diagnostic devices are mostly connected with the main engine operation and concern such problems as:

- thermal load analysis of piston-cylinder blocks
- combustion process and fuel injection analysis
- wear analysis of rings, liners and bearings.

The portable diagnostic devices serve usually for determining a technical state of the main engine elements, pumps, compressors, master switches and cable lines.

The computer-aided diagnostic devices realize both the previously mentioned functions on the basis of specialized microprocessor systems.

The testers are the devices destined mainly for the detecting failures of the panels and printed circuit boards which are components of the automatic control systems.

Some examples of the systems are presented hereafter.

One of the basic problems related to diagnostics of the combustion engines is the thermal analysis of the piston-cylinder block. Evaluation of the thermal load of the block is a difficult problem and it requires determining the field of real instantaneous temperature values. The problem can be solved by means of NSFI approximate procedure [12] or by the use of THERMAL LOAD ANALYSER [11]. The NSFI procedure is an analytical way of determining the temperature field of the combustion chamber [12], based on the following formula:

$$t_n = A + B\frac{t_d^{1.25}\,p_i^{1.5}\,n^{0.35}}{p_d^{1.2}} \qquad (1)$$

where:

t_n	-	temperature at a given point of the combustion chamber
A, B	-	empirical factors
p_d , t_d	-	turbo-charged air parameters (pressure, temperature)
n	-	engine speed
p_i	-	average indicated pressure

If there is no computer on board, a graphical form of the criterion (1) is recommended, shown in Fig.8.

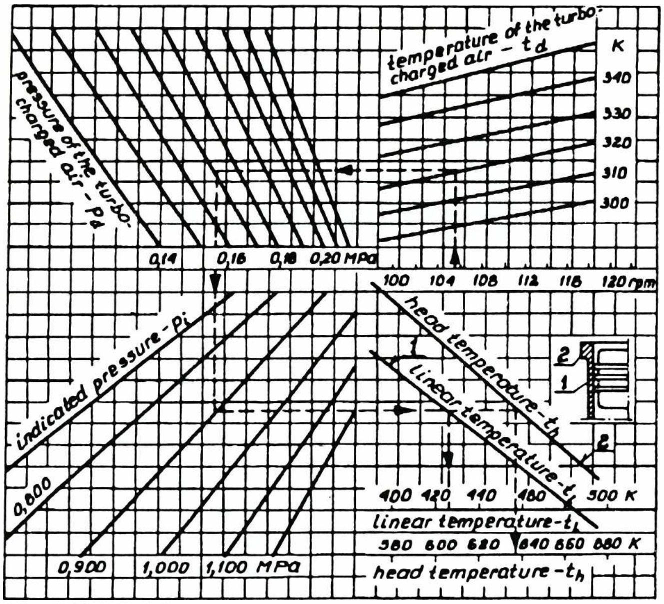

Fig.8. Nomogram for determining the cylinder liner temperature according to the NSFI procedure [12]

Another method is based on the direct temperature measurements taken at selected point of the combustion chamber by means of installed temperature sensors (Fig.9a).

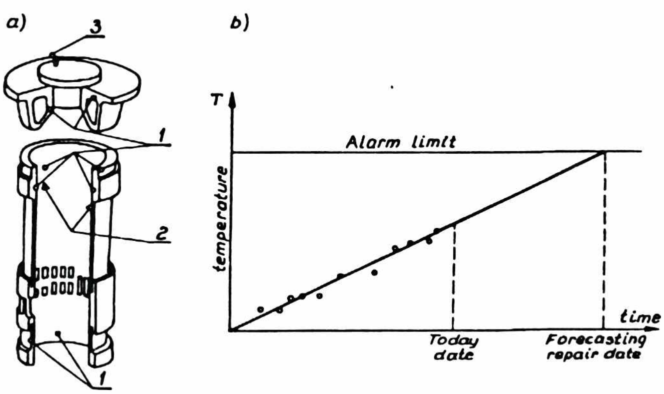

Fig.9. Thermal load analyzer and its practical application
a) An example of temperature sensors layout used in AUTRONICA thermal load analyzer [11]: 1 - temperature sensors, 2 - liner wear sensors, 3 - indicator cock
b) Prediction scheme of repair date of internal combustion engine element on the basis of thermal load measurements

In this method the real local temperature values can be compared to the reference values calculated in accordance with the formula (1). On this basis the temperature-time distribution for engine elements, and time to repair or replacement may be predicted (Fig.9b). The presented method and means for its performing is an example of the so called protective or passive diagnostics. Opposite to it is the active diagnosis where the device exploitation process is optimized. For example, FUEL ECONOMIZER device of SAL [11] made it possible to optimize ship's route from the fuel consumption point of view, on the basis of the measurements of ship speed, trim, specific fuel consumption, torque, and main engine shaft revolution, and with weather changes, cargo and main engine characteristics accounted for.

TNP- 6 microprocessor torque and power meter, implemented by Maritime Academy, Gdynia, can fulfil similar functions [13].

The tester of the main switchboard [14], which belongs to the portable diagnostic devices, allows for testing its measurement and control equipment, generator protection systems and measuring circuits of generator voltage control. The testing procedure does not require removing any apparatus from the main switchboard. The basic idea of the testing procedure is to disconnect the main switchboard and generator circuits off the ship network and to connect them to the tester, which is supplied from the land electric network. The tester makes it possible to control and adjust electric parameters such as current, voltage, frequency and phase angle in a required range.

CONCLUSIONS

● The exploitation and diagnostic measurements fulfil an important role for safety and effective fuctioning the ship power system. This is realized by means of measuring the electric and non-electric quantities necessary for ensuring proper values of parameters of electric energy during its production, distribution and usage, and also for correct operation of the involved devices and processes.

● Nowadays new measurement methods and techniques, as well as new sensors and converters (e.g. optional sensors) have been developed.

● Moreover, many new designs of measuring systems with sensors of an improved resistance against disturbing factors are available.

● New techniques of signal transmission and procesing such as: optoisolator techniques inclusive of fiber optics, digital signal processing, specialized sophisticated software are generally accepted e.g. in the area of the main engine diagnostics to minimize fuel consumption, or to automatically control the ship power station.

NOMENCLATURE

C - capacitor
DZ - Zener diode
f_g, f_{sg} - generator and shaft generator freguency, respectively
Δf_g, Δf_{sg} - generator and shaft generator frequency changes, respectively
F - fuse
R - resistance
R_p - potentiometer
T - transistor
U_g, U_{sg} - generator and shaft generator voltage, respectively
ΔU_g, ΔU_{sg} - generator and shaft generator voltage changes, respectively
U_n, f_n - nominal value of network voltage and frequency, respectively
ΔU_n, Δf_n - network voltage and frequency changes, respectively
x - current magnitude
υ - temperature
ψ_g - phase shift between U_n, U_g voltages
ψ_{sg} - phase shift between U_n, U_{sg} voltages

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