



**RESEARCH ON ENERGETIC PROCESSES IN A MARINE DIESEL  
ENGINE DRIVING A SYNCHRONOUS GENERATOR FOR  
DIAGNOSTIC PURPOSES  
PART 1 – PHYSICAL MODEL OF THE PROCESSES**

**Aleksy Cwalina**

*Gdańsk University of Technology  
Ul. Narutowicza 11/12, 80-950 Gdańsk, Poland  
e-mail: A.Cwalina@amw.gdynia.pl*

**Marcin Zacharewicz**

*Polish Naval Academy  
Ul. Śmidowicza 69, 81-103 Gdynia, Poland  
Tel.: +48 626 23 82  
e-mail: M.Zacharewicz@amw.gdynia.pl*

**Abstract**

*In the paper a physical model of certain processes taking place when marine diesel engine is driving a synchronous generator is presented. This physical model will be a basis for a mathematical model realization in a form of equations describing the relationships between the designated parameters of the diesel engine and the generator. The method of theoretical and operational investigations which enables identification of the technical condition of the set is presented. Systematic collecting the results in the database will allow to refine the model, and to conclude about the technical condition of real objects.*

**Keywords:** *diagnostic, marine diesel generator*

**NOMENCLATURE**

**PARAMETERS**

F	- force
I	- current
J	- mass polar moment of inertia
i	- enthalpy
M	- torque
m	- mass
$\dot{m}$	- mass flow rate
p	- pressure
R	- gas constant
$\dot{Q}$	- heat flux
S	- area

T	- temperature
U	- voltage
w	- linear velocity
V	- volume
$\varepsilon$	- generalized losses
$\kappa$	- isentropic exponent
$\omega$	- angular velocity

## ABBREVIATIONS AND INDEXES

cyl.	- cylinder
g	- gas
K	- connecting rod
L	- phase
oK	- connecting rod response
oMP	- engines machinery response
oP	- generator response
oWK	- crankshaft response
p	- back pressure
P	- generator
pk	- exhaust gases in the manifold
sp	- exhaust gases in the outlet channel
t	- piston
wk	- crankshaft
*	- total value of parameter
1,2,3...n	- subsequent cylinder, phase, etc.

## 1. INTRODUCTION

One of the maintain problems of the generating set consisting of the marine diesel engine and the synchronous generator is to determine their technical condition. The generators on the ship are frequently driven by a combustion engines that are not equipped with indicator valves. Such engines with limited monitoring susceptibility, are operated according to so-called overhaul life strategy. The current trend is to implement economically advantageous operating strategy according to the technical condition of the ship's mechanisms and appliances. Such attempts have also been made with respect to diesel-electric generating sets. Technical condition of selected elements of the structure design based on endoscopic examination [4] and vibration testing was evaluated. An alternative method currently developed by the authors of the paper is to determine the technical state of the ship generating set by means of testing pressure pulsations in the exhaust gas channels, phase-to-phase generator voltages, and vibrations of selected parts of the engine and the driven generator [2, 3].

## 2. PLAN AND METHODOLOGY OF RESEARCH

The first stage of research directed on developing methods for evaluation technical condition of the generating set of the ship power station was to develop a research plan. Similar plans were worked out in previous works by the authors, for example [2, 3, 5, 8] in the form of block diagram presenting successive stages of the investigation. The diagram

shows the interactions between particular stages of work. In general, the starting point for the development of the plan is a real object, in this case a diesel- electric generating set consisting of a combustion engine type SW 400 and synchronous generator GCPf-94c/1. Basic technical data of the investigated engine are shown in Table 1.

Table 1. Technical characteristic of diesel engine type SW 400 [9]

Rated output	54,06 kW	Injection type	Direct
Rated crankshaft Speed	1500 rpm	Injection order	1-5-3-6-2-4
Number of cylinders	6	Injection pressure	16,18 – 16,67 MPa
Piston stroke	120,65 mm	Specific fuel consumption	190 g/kWh
Cylinder bore	107,19 mm	Intake valve opening commencement	10 <sup>0</sup> before the TDC

General view and schematic diagram of the generating set is shown in Figure 1.

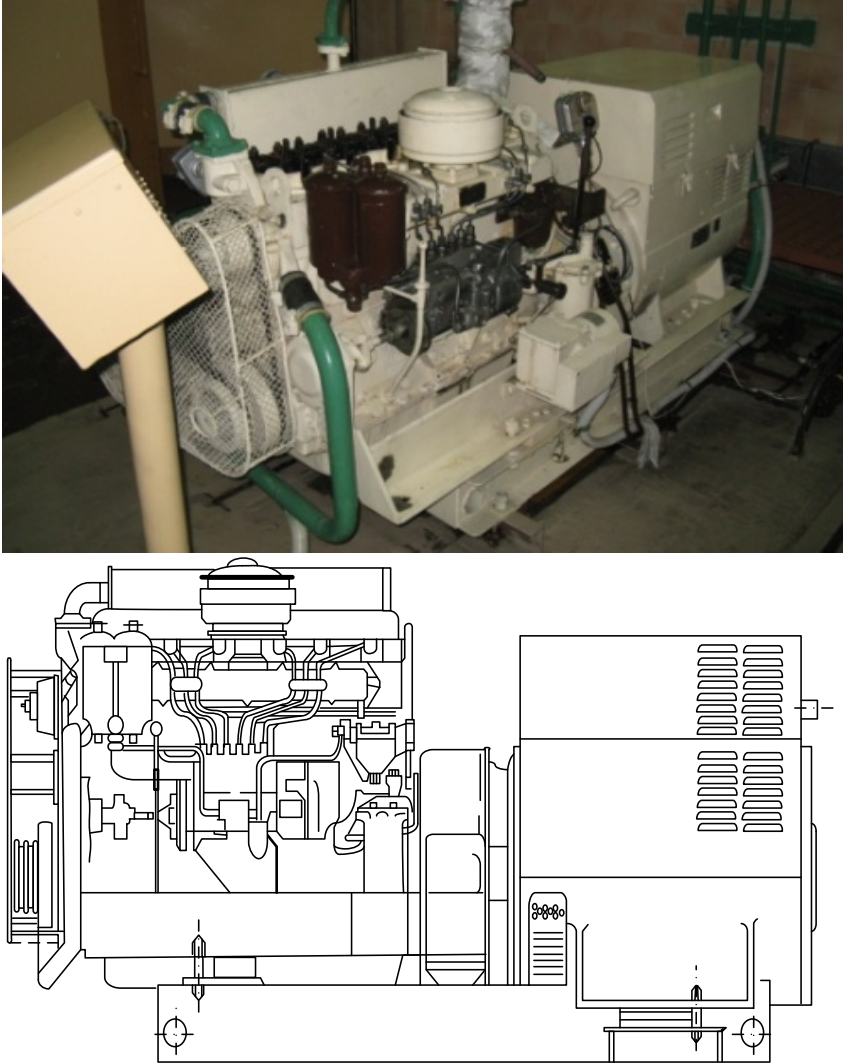


Fig.1. General view and schematic diagram of the diesel-electric generating set being the object of the research

In the proposed research plan the real object is a base for developing a physical model of the selected processes occurring in diesel-electric generating set. In this physical model the possibility to simulate damages to the combustion engine and synchronous generator by means of changing values of selected structural parameters was taken into account [6]. The physical model is a base for preparing a mathematical model in a form of set of equations describing the interdependence between selected mechanical, electrical, and gas dynamical parameters.

The equations of the mathematical model recorded as a computer programme will allow for conducting the model studies of the effects of simulated damage on the waveforms of the generating set analyzed energetic parameters. At the same time we are going to conduct the research on the real object, generating set. There will be introduced the same known and recognizable damage to the model and the real object. The results obtained from simulation studies and research conducted on the real object will be compared in the time domain and frequency domain. Following the results of the comparative analysis the adequacy of the physical model and based on it the mathematical model will be evaluated. If the simulation results will differ to a greater extent than assumed by the results of a real object, the physical model will be modified to increase its relevance. The results of all studies, both the model and simulation will be collected in a database technical condition – symptom. Creation of such a comprehensive database will help in the future to identify the technical state of the generating set and the proper diagnosis. The proposed flow chart of the investigation is shown in Figure 2 [1].

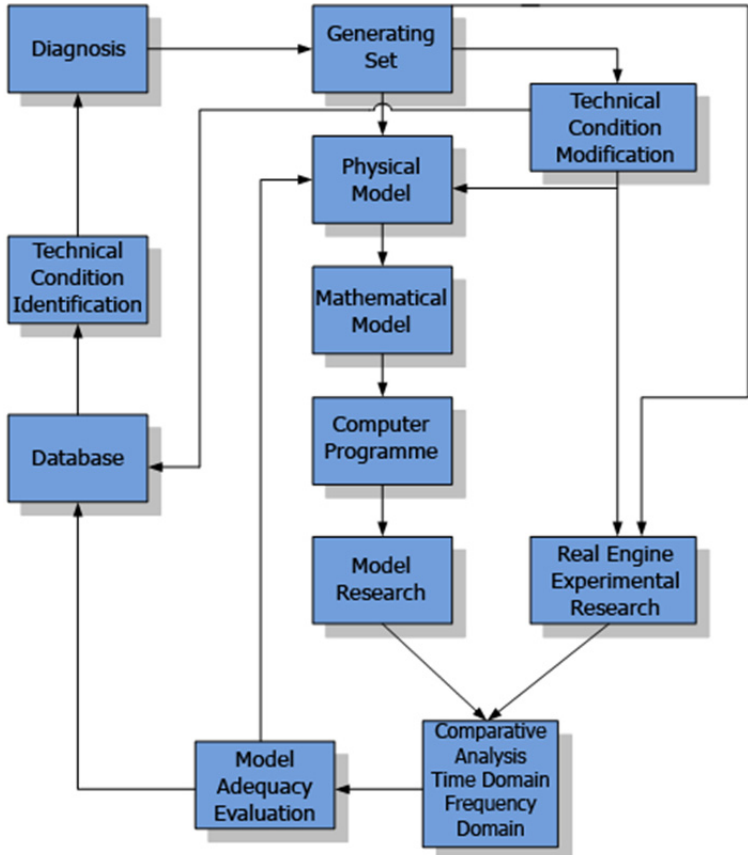


Fig.2. Diagram of realization the diagnostics research

### 3. A PHYSICAL MODEL

The proposed physical model is a certain conception of theoretical representation of phenomena and processes which occur in considered real object – generating set. This model includes a set of assumptions that define a simplified image of the investigated object, and takes into account whole physical quantitative and qualitative relationships. The degree of model simplification results from both objective and subjective factors. The objective factors include the state of the art – the possibility to identify all the phenomena and processes, and competency to describe them by means of appropriate relationships. The subjective factors are the needs and technical conditions for the model analysis of the given object (generating set). In general, only selected stages of considered processes are modeled, with far-reaching simplification [6].

In this model, the physical input parameters are:

- gas pressure in engine cylinders  $p_{cyl} = f(\alpha)$ ,
- cylinder volume  $v_{cyl} = f(\alpha)$ ,
- gas parameters inside cylinders, such as gas constant  $R_{cyl} = f(\alpha)$  and isentropic exponent  $\kappa_{cyl} = f(\alpha)$ ,
- engine load expressed by generator voltage and current  $U, I = f(\alpha)$ .

All these parameters are a function of the engine crank angle  $\alpha$ . The next group of input parameters are the design parameters of the structure of the generating set (diesel engine, synchronous generator, coupling). The main of them are the piston diameter, connecting rod length, and crank arm length. Another group of parameters are connecting rod, piston, piston pin masses distribution, rotating elements moments of inertia (engine crankshaft, clutch, rotor of the generator, driven mechanisms etc.).

Output parameters are:

- exhaust gas pressure in the outlet channel  $p_{pk}^* = f(x, \tau)$ ,
- exhaust gas temperature in the outlet channel  $T_{pk}^* = f(x, \tau)$ ,
- speed of movement of peak amplitude exhaust gas pressure wave  $w_{pk} = f(x, \tau)$ .

All these exhaust gas parameters in the outlet channel are a function of time and the channel length (coordinate cross-section in which they are measured). The last group of the output parameters are those measured on the synchronous generator driven by the diesel engine. In the presented model instant values of phase-to-phase voltages as time functions are taken into account. The proposed physical model is shown in Figure 3.

In this model the engine cylinder were treated as zero-dimensional objects i.e. independent variable for them is only time of the process. Engine cylinders are able to store a mass of thermodynamic medium marked as  $m_{cyl}$ . The input parameters relating to the engine cylinders are pressures inside cylinders, cylinder volumes and parameters of working medium inside cylinders such as individual gas constant and isentropic exponent. In the model of the engine cylinder section mass of the piston with connecting rod was taken into account, and marked as  $m_T$ , and considered as carrying out reciprocating motion only.

Engine cylinders output thermodynamic parameters being the input parameters for the exhaust channel are pressure  $p_{cyl}^*$ , and temperature  $T_{cyl}^*$  of the exhaust gases, their mass flux

$\dot{m}_{cyl}$ , enthalpy flux  $i_{cyl}^*$ , and speed of moving working medium  $w_{cyl}$ . Additionally, the model takes into account influence of the gas pressure from the outlet channel on cylinder sections  $p_p^*$ . Exhaust gas output channel is modeled as a one-dimensional object, which means that the independent variables are time and channel length determining the position of control cross-sections in which exhaust gas measurements are taken. The physical model takes into account dynamics of elements reciprocating and those in rotating motion. For this purpose weight distribution of selected structural elements of the engine and generator were taken into consideration.

This refers mainly to the piston with piston pin and rings involved in reciprocating motion, connecting rod that moves in a mixed way – its one part is reciprocating and the other is rotating, and engine crankshaft with a flywheel that rotate together with the rotor of the generator. The complicated character of movement of the connecting rod can be examined as a sum of a motion of reciprocating mass and a motion of rotating mass, calculated by means of the “weighing system” [7]. In the model gas forces acting on the piston  $F_g$  and connecting rod forces  $F_{oK}$  were considered as well as moments of inertia of the piston-crank mechanism  $J_K$ . Engine crankshaft is another element of the model. Turning moment acting upon the crankshaft, originating from gas forces, is a product of these forces and the length of the crankshaft crank  $M_{WK}$ . In a similar way as in the case of the piston-connecting rod set, in the assembly connecting rod-crankshaft the moment  $M_{oWK}$  from the crankshaft acting on the connecting rod was taken into account. It is assumed in the model that all the masses and moments of inertia of mechanisms driven by the engine are treated globally.

Torque derived from the crankshaft is transmitted to the generator rotor  $M_{WK}$ . The generator influence on the engine is the load torque  $M_{oP}$ . It was assumed in the model of the generator that the only rotating mass is the mass of the rotor  $m_p$ . The synchronous generator unit produces three-phase alternating voltage with a frequency of 50Hz which meets double frequency of rotating speed of the engine crankshaft. Electric load of the generator brings about passage of current  $I_L$  at the assumption that phase-to-phase voltage is  $U_L$ . As the generator load is resistive, power can be calculated as the product of voltage and current because power factor is equal to 1. Consumption of power produced by the synchronous generator is the source of the diesel engine load torque  $M_{oP}$ .

There are feedback loops in the model because increasing of the generator load results in decreasing of electric voltages in phases  $L_1$ ,  $L_2$  and  $L_3$  what in turn increases generator excitation current. This process is controlled by AVG (Automatic Voltage Regulator) which senses the generator output voltage and acts to alter the field current to maintain the voltage at its set value  $V_1$ ,  $V_2$ , and  $V_3$ . As a result of such a regulation the generator voltage increases or decreases to  $\pm 2,5\%$  (or better), so changing the angular speed of the diesel crankshaft  $\omega$ . The angular speed is an input signal to the speed governor of the diesel engine that, by means of changing the fuel charge, keeps the speed at the set value. This speed is an input to the speed governor of a piston engine, which is a drop in the value of increasing the flow of fuel supplied to the engine cylinders thus increasing the angular velocity of the crankshaft to the specified value.

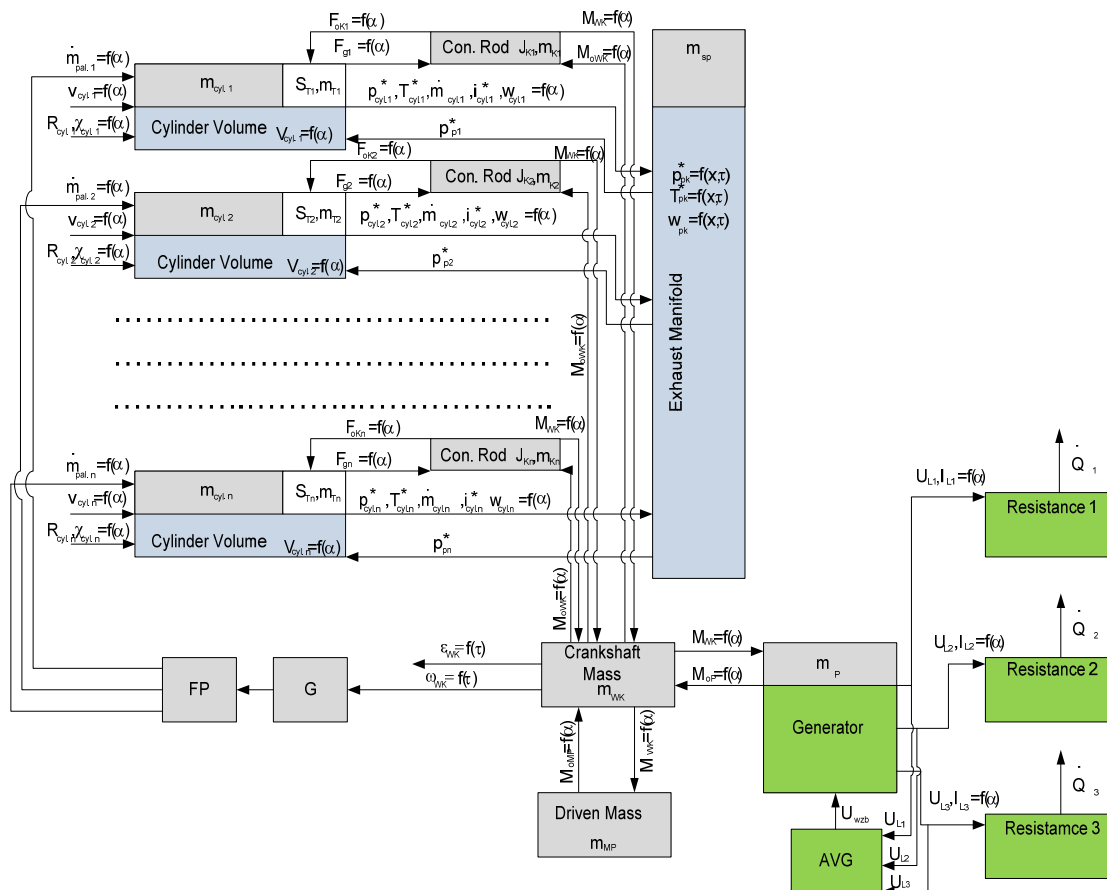


Fig.3. Physical model of energetic processes taking place in the generating set diesel engine – synchronous generator

#### 4. SUMMARY

The presented above research plan and physical model of the marine generating set should allow to work out a non-invasive method for evaluation the technical condition of a diesel electric set, and further a diagnostic methodology, when the engine is not equipped with indicator valves. It is estimated that diagnostic inference there will be possible about combustion process in engine cylinders. Technical state of the engine fuel system, its regulation and the tightness of the set piston-piston rings-cylinder liner, and the condition of the timing system, have the greatest influence on it. Moreover, it will be possible to assess the technical condition of the electrical elements of the synchronous generator and its bearings.

#### REFERENCES

- [1] Cannon, R. h., *Dynamika układów fizycznych*, WNT, Warszawa 1973.
- [2] Cwalina A., Zacharewicz M., *Preliminary investigations of generating set of the ship's power station in the aspect of diagnosing selected parts of its construction structure*, Combustion Engines nr 3/2011 (146)
- [3] Cwalina A., Zacharewicz M., *The conception of diagnosis in auxiliary diesel engine at limited monitoring susceptibility in automated ship power plant*, Polish Journal of Environmental Studies 2011, Vol 20, No 5A/2011
- [4] Korczewski Z., *Endoskopia silników okrętowych*, AMW, Gdynia 2008

- [5] Korczewski Z., Zacharewicz M., *Metodyka diagnozowania silników okrętów wojennych o ograniczonej możliwości pomiaru ciśnień wewnątrzcyldrowych na podstawie wyników badania procesów gazodynamicznych w układzie turbodoładowania*. Opracowanie w ramach projektu badawczego nr: 0T00B02129
- [6] Sobieszczański, M., *Modelowanie procesów zasilania w silnikach spalinowych*, WKŁ, Warszawa 2000
- [7] Szczeciński S., *Lotnicze silniki tłokowe*, MON, Warszawa 1969
- [8] Zacharewicz M., *Metoda diagnozowania przestrzeni roboczych silnika okrętowego na podstawie parametrów procesów gazodynamicznych w kanale zasilającym turbosprężarkę*, Rozprawa Doktorska, AMW, Gdynia 2009.
- [9] Dokumentacja techniczno - ruchowa zespołu prądotwórczego ZE500/52