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PHYSICAL MODEL OF ENERGETIC PROCESSES IN THE MARINE DIESEL ENGINE

ABSTRACT

The paper describes the preliminary physical model of gas-dynamic processes that take place in the cylinder of marine diesel engine. The model is a part of the work undertaken at the Institute for Construction and Exploitation of Ships at the Polish Naval Academy. The physical model is the basis for the development of a mathematical model of marine diesel engine, which will be useful for determining the energy efficiency of Polish ships, as well as for diagnostic purposes.

Key words:
marine diesel engine, physical model, diagnostics, modeling.

INTRODUCTION

The physical processes that take place in combustion engines are an extremely complex issue. Modeling of such processes is undertaken both by research groups from Poland [2, 5–8] and from abroad [3]. Commercial programs have been created on the basis of their studies and are frequently used for designing purposes. Unfortunately, engineering software is extremely complex and the process to change input parameters of such programs requires work and is time-consuming. In addition, the process of solving a models' equations (source code) is arduous as well. Due to these limitations, the Institute of Ship's Construction and Exploitation of the Polish

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Naval Academy has developed a simplified model, that allows easy modification all input parameters and solving the equations, with time-saving desired accuracy.

The developed model can find application in ship's engine room energy efficiency analyses and ship's reciprocating engines (both main and auxiliary) diagnoses. The ease of input and modification geometrical parameters allow conducting analyses of various engine types in miscellaneous loads and modeling changes engine's technical condition.

The physical model presented in the paper is a modification of the previously presented model. This modification results from implementation of test pattern shown in figure 1. Modifications are a direct result of the model validation process based on real-world research and the desire to increase versatility of the model.

RESEARCH PLAN

At the beginning of creating a model is to define purposes. It is connected with modeling scope and its accurancy. In case of the designed model, the basic premise was that it would be used in analyzing ship's energy efficiency and engines diagnoses. Such a premise forced following criteria to be met:

- the ability to quickly and easily modify a modeled engine's constructional structure (which would allow for almost every Polish Navy's engine to be modeled);
- the ability to quickly and easily modify input parameters (which would allow for the model's equations to be solved for various engine exploitation conditions);
- the ability to conduct calculations swiftly (which also has a profound effect on their accuracy);
- the ability to modify the structural parameters of various engine's cylindrical sections (in order to simulate known and recognizable damages) [4, 5].

A research plan has been developed on the basis of these criteria (approach according to Cannon). It is shown in the algorithmic form in the figure 1.

In the first stage, on the basis of a real object, a physical model that enfolds fundamental functional dependencies between the modeled object's structural elements and engine's energetic parameters relations was created. A mathematical model, based on the physical one, that contains the description of the aforementioned dependencies in the form of balance equations, was developed afterwards.

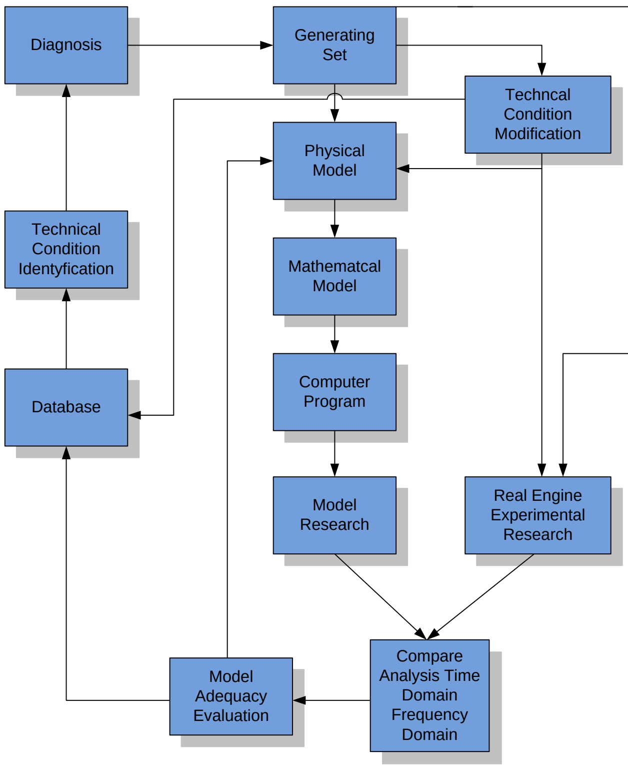

Fig. 1. The research schedule [1]

The mathematical model's equations are the basis for a computer program that allows for their expeditious solving. The time courses of the engine's energetic parameters are the result of the conducted simulations. Parallel experimental research on a real object is carried out and engine's parameters are measured. Both in the case of the model research and the experimental research engine's technical structure changes and work parameters are simulated. An analysis of both the model and experimental researches outcomes allows for the model to be validated or, if needs be, corrected. All of the outcomes are gathered in the technical condition--symptom database.

PHYSICAL MODEL

The physical model is a certain theoretical concept mapping of processes and phenomena occurring in the modeled object. It is a set of assumptions that define a simplified image of the object of research and includes all quantitative and qualitative physical compounds [grant].

The developed model's input parameters are [2, 9, 10]:

– the parameters of air supplying an engine such as: inlet air pressure p_{ot}, air temperature T_{ot}, individual gas constant R;
– engine power indication value or air excess coefficient;
– cylinder's fuel supply parameters: mass flow $\dot{m}_{pal}$, temperature T_{pal}, calorific value W_{pal}, based on the coefficient of excess air, its fuel dose is injected into the cylinders;
– exhaust pressure, preventing the outflow of an engine exhaust duct.

Another group consists of engine's structure parameters such as:

– a number of engine cylinders;
– an arrangement of engine cylinders (in-line, *V*);
– cylinder order;
– a length of a connecting rod r, connecting rod length l, a piston diameter D, a height of the combustion chamber;
– an number of engine strokes;
– information on whether an engine is turbocharged or none;
– engine timing and geometry of intake and exhaust systems.

An assumption has been made, that each of the aforementioned input and structural parameters can be modified in every way, which allows for conducting model research for almost any diesel engine. Moreover, it is possible to conduct research in any exploitation environment (torque load, crankshaft rotation speed). The modification of each of a cylinder stations makes carrying out diagnostic research (through simulating known and recognizable damage and the assessment of its impact on the analyzed engine's energetic parameters time courses possible. States of inadequacy can be simulated consisting of modifying the fuel dose for the selected cylinder, simulating leaks in a piston-ring-cylinder system, modification of a cross--section of inlet and outlet valves, modification of injector hole cross-sectional area.

The developed model assumes, that engine's cylinders are treated as 0-dimensional objects, for which time is an independent variable. Engine's cylinders allow for the thermodynamic factor's mass accumulation, which is symbolized as mass m_{cyl}. An engine's rotating elements are treated as an alternative mass with certain inertia, while the reciprocating masses are all treated separately.

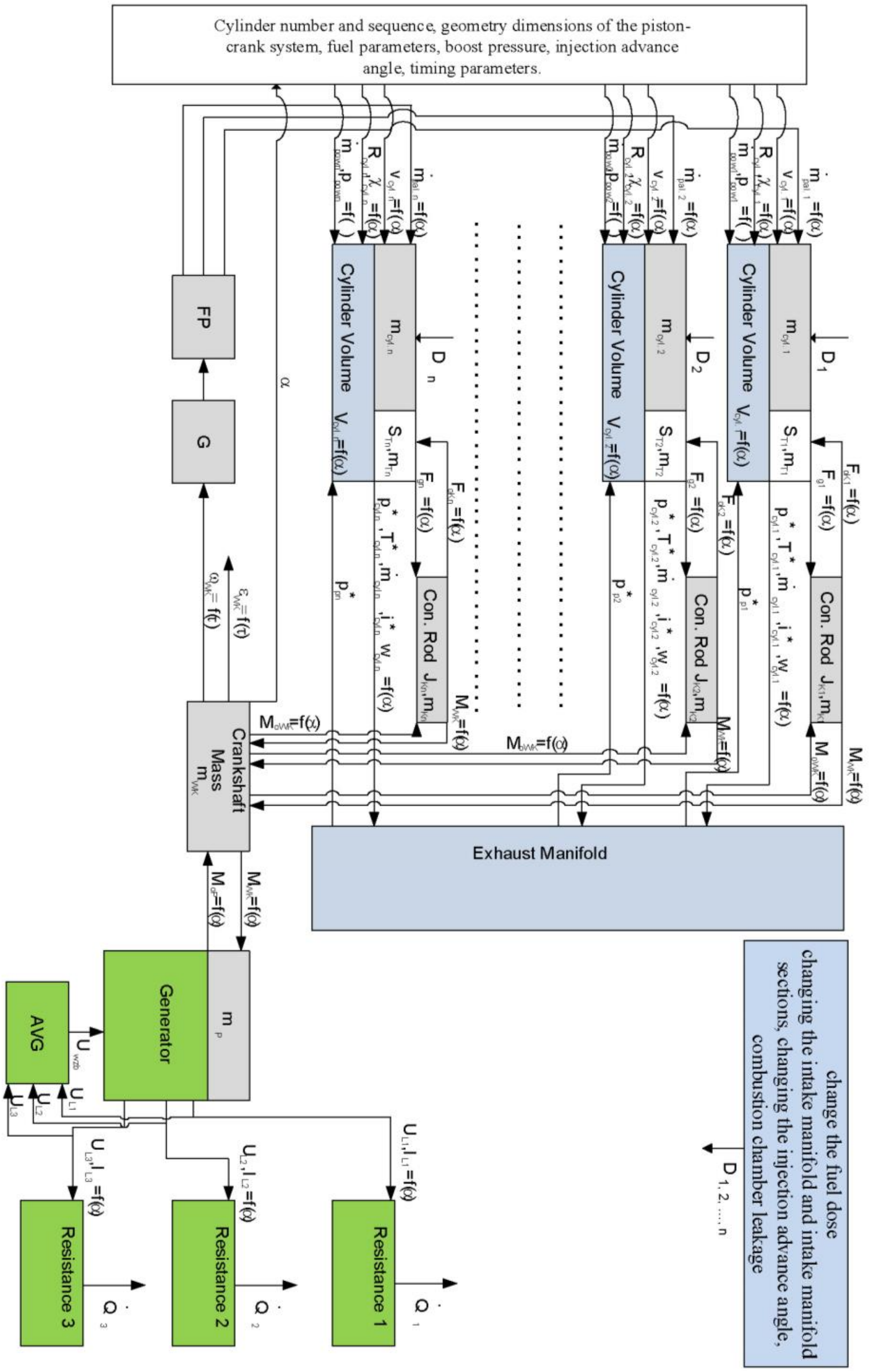

Fig. 2. The graphical presentation of the physical model of selected physical processes occurring in marine ignition internal combustion engine [2]

An engine's cylinders input parameters are: air supply parameters i.e. its pressure, temperature, gas constant and the individual heat capacity ratio. Furthermore, the cylinder's input parameter is the fuel's flow considered as a function of the crankshaft angle (determined in successive iterations, until reaching a assumed power). Gas-dynamic parameters of the thermodynamic factor are calculated within the cylinder. They are dependent on its chemical composition, its capacity considered as the aforementioned function, the energy supplied with the fuel and many other factors.

The factor's output parameters are determined on this basis (in the outlet valve's plane). It is worth noting, that they can only be assessed when the outlet valves are open. The parameters of the factor leaving the cylinders are as follows: pressurep^*_{cyl}, temperatureT^*_{cyl}, mass flow $\dot{m}_{cyl}$, enthalpy i^*_{cyl}, velocity w_{cyl}.They are at the same time the exhaust channel input parameters. While determining the factor's parameters in both cylinders and the inflow channel, the factor's flow resistance, marked as p^*_p for cylinders, as the pressure counteracting the exhaust flow p^*_{wyl}, were taken into account. The model also takes into calculations the impact of the piston-crank on the parameters of the thermodynamic factor in the cylinders of the engine. This interaction takes place through the piston head acted on by the intra-cylinder factor's gas--dynamic forces F_g and the inertia forces of the masses carrying out reciprocating and rotary motion F_{oK}.Torques transmitted by the cranks on the crankshaft and the torque that is the result of the crankshaft rotary motion resistance and the power-take resistance, both influence the inertia force values on the crankshaft M_{WK}. The resistance movement of the crankshaft is influenced by the process of frictions that take place at the nodes bearing the crankshaft and suspended mechanisms.

SUMMARY

In the article, the model of physical processes that take place in ship's reciprocating combustion-ignition engine is presented. It is also constitutes one of an engine room's energy efficiency assessment stages. On the basis of the presented assumptions, a mathematical model of the physical processes that occur in such an engine was developed. In the future, balance equations of the mathematical model will be implemented as a computer program, which will allow for their quick solving. The mathematical model was designed in a way that allows for its diagnostic appliance. This is accomplished by considering the feasibility of modifying a structure of an engine, thus simulating know and recognizable damage.

LIST OF MOST IMPORTANT MARKINGS AND ABBREVIATIONS

F — force
i — enthalpy
M — torque
m — mass
$\dot{m}$ — mass flow rate
p — pressure
R — gas constant
T — temperature
w — linear velocity, applies to rotating masses
W — calorific value of fuel
λ — excess air ratio
τ — time
ω — angular velocity
cyl — applies to cylinders
FP — fuel pump
g — applies to gas forces
G — rotational speed controller
K — applies to the connecting rod
o — applies to reaction forces
ot — applies to the environment
P_{wyl} — applies to pressure to counteract the outflow
pal — applies to fuel
pk — applies to exhaust gas channel
WK — applies to the crankshaft

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MODEL FIZYCZNY PROCESÓW ENERGETYCZNYCH ZACHODZĄCYCH W OKRĘTOWYM TŁOKOWYM SILNIKU SPALINOWYM

STRESZCZENIE

W artykule opisano model fizyczny procesów gazodynamicznych zachodzących w cylindrach okrętowego tłokowego silnika spalinowego o zapłonie samoczynnym. Prezentowany model powstał w wyniku prac badawczych prowadzonych w Instytucie Budowy i Eksploatacji Okrętów Akademii Marynarki Wojennej. Stanowi on podstawę do opracowania modelu matematycznego, który znajdzie zastosowanie w badaniach nad efektywnością energetyczną siłowni okrętowej oraz będzie użyteczny w opracowywanych w Instytucie bezinwazyjnych metodach diagnostycznych silników okrętowych.

Słowa kluczowe:
okrętowy tłokowy silnik spalinowy, model fizyczny, diagnostyka, modelowanie.