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DIAGNOSTIC INFORMATION ANALYSIS OF QUICKLY CHANGING TEMPERATURE OF EXHAUST GAS FROM MARINE DIESEL ENGINE PART I SINGLE FACTOR ANALYSIS

Patrycja Puzdrowska*
Gdańsk University of Technology, Poland
* Corresponding author: *patpuzdr@pg.edu.pl (P. Puzdrowska)*

ABSTRACT

In this paper, attention was paid to the problem of low controllability of marine medium- and high-speed engines during operation, which significantly limits the parametric diagnosis. The measurement of quickly changing temperature of engine exhaust gas was proposed, the courses of which can be a source of diagnostic information. The F statistic of the Fisher-Snedecor distribution was chosen as a statistical tool. Laboratory tests were carried out on the bench of a Farymann Diesel engine. The tests consisted of introducing the real changes in the constructional structure of the considered functional systems of the engine. Three changed parameters for the structure were reviewed: the active cross-sectional area of the inlet air channel, injector opening pressure and compression ratio. Based on the recorded plots of the quick-changing temperatures of the exhaust gases, three diagnostic measures were defined and subjected to statistical tests. The following data were averaged over one cycle for a 4-stroke piston engine operation, (1) the peak-to-peak value of the exhaust gas temperature, (2) the specific enthalpy of the exhaust gas, and (3) the rate of increase and decrease in the values for the quick-changing exhaust gas temperature.
In this paper will present results of the first stage of the elimination study: the one-factor statistical analysis (randomised complete plan). The next part will present the results of the second stage of studies: two-factor analysis (block randomised plan), where the significance of the effect of changing the values of the structure parameters on the diagnostic measures was analysed in the background of a variable engine load.

Keywords: marine diesel engine, exhaust gas temperature, diagnostic information, F-statistic of Fisher-Snedecor distribution

INTRODUCTION

The exhaust gas temperature is the basic diagnostic parameter for a marine diesel engine. This is the case for the one providing the main propulsion for the ship and the one that is an element of the power plant of the ship. The exhaust gas temperature is a parameter that characterises the quality of the fuel chemical energy transformation into mechanical energy as a result of complex physicochemical processes that occur in the combustion chamber of the engine. The exhaust gas temperature determines the efficiency of the thermodynamic processes taking place in the separated gas spaces in the thermo-fluid system of the engine during transport of the working medium. Diagnostic information about the temperature of exhaust gases is strictly dependent on the place and precision of the measurement.

In this case, the object of the diagnostic tests is the construction elements that enclose the working spaces of a marine diesel engine (combustion chamber and channels of inlet air and exhaust gases) and also the injection equipment. Most marine diesel engines have strictly defined places for standard exhaust gas temperature measurement because of the requirements of classification societies [40, 41, 42, 43, 44]. For the main engines that compose the propulsion system of a ship, a measurement of the exhaust gas temperature after each cylinder is required as well as a calculation of its deviation

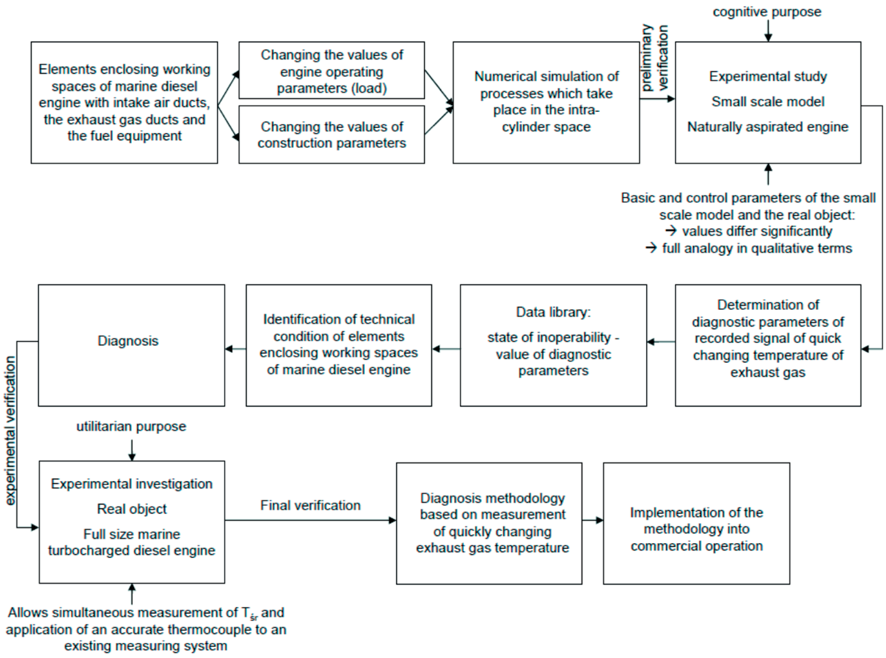


Fig. 1. Scheme for the study of the thermal-flow processes in the exhaust gas channel for the diagnostics of elements enclosing the working spaces of a marine diesel engine

from the average value for the whole engine (or cylinder block) [40]. In the case of marine diesel engines driving generators with a power output of more than 500 kW per cylinder, a measurement of the exhaust gas temperature after each cylinder is required [41]. When the engine is equipped with a pulse turbocharging system, the standard exhaust temperature measurement locations are before and after the turbocharger turbine [42]. For this purpose, traditional thermocouples with a large measurement inertia (time constants of the order of tenths of a second and more) are used and from which an average value for the periodically changing temperature of the exhaust gas flow is obtained [9]. The exhaust gas temperature measured at steady state conditions of the engine is usually recorded as a static value. When analysing the diagnostic information of this parameter in terms of depth and reliability of the diagnosis of the engine technical condition, it has been observed that dynamic measurements have a higher value. The observation of microdynamic processes (quick-changing processes) within a single working cycle of an engine in the steady state allows for a more detailed diagnosis. The average temperature recorded with standard thermocouples and its deviation by the permissible value set by the manufacturer does not provide as much information about the course of the combustion process, the technical condition of the fuel supply system, and the space enclosing the combustion chamber because of the quick-changing temperature and diagnostic parameters based on it. Therefore, it is possible to place a special thermocouple in the exhaust for a standard exhaust gas temperature measurement to obtain more diagnostic information, where the time constant is tens or even several milliseconds. At the same time, it must be possible to observe the average value of the exhaust gas temperature during engine operation. This requirement is not a major operational problem currently because of portable diagnostic systems [9, 34].

In the research carried out by the author of this paper, the thermodynamic processes that take place in the intra-cylinder spaces of a diesel engine were analysed, where the engine was treated as a generator with a quick-changing exhaust gas temperature. The experimental investigations were carried out on a single-cylinder naturally aspirated engine, which is a small-scale model of a real object, i.e., a full-size turbocharged marine engine. The observed basic and control parameters differed significantly (small scale effect); however, there was a significant qualitative analogy between the thermodynamic processes occurring in both engines (Fig. 1).

The problem of quick-changing gases temperatures is being dealt with by many research teams. Some of these were based, for example, on H. Pfriem's 1936 proposal to use two thermocouples of different diameters [1, 3, 4, 5, 6, 19, 20, 21, 28, 31]. The work of these authors extended the metrological knowledge related to the measurement of quick-changing temperatures of gases flowing at high velocities on the order of several tens of m/s, which occurs in the exhaust gas duct of a piston engine [9]. Moreover, docent S. Rutkowski made the first efforts in Poland to measure the quick-changing temperature of exhaust gases from a diesel engine for diagnostic purposes [29]. The main aim of the research was to determine the diagnostic relations between a decrease in the compression pressure of the factor in the cylinder and the dynamics of the changes in the observed temperature of the exhaust gases. Many authors work on the reconstruction of the exhaust gas temperature of a diesel engine in an analytical way that is based on an indicator diagram recorded during experimental tests [8, 22, 33, 35, 38]. These authors proposed methods for diagnosing marine engine workspaces, but none of them did it based on the direct measurement of the exhaust gas temperature. There are also research works available in the specialist literature, where the authors determined the exhaust gas temperature analytically with optoelectronic measurements of the flame temperature in the combustion chamber of a laboratory engine; a linear dependence between its temperature and exhaust gas temperature was indicated [12]. A very important aspect of modern research in the field of marine engines is ecology. The analyses of the influence of various factors related to engine operation on the emission of exhaust gases are carried out. Application of alternative fuels or new structural solutions is aimed at minimizing the influence of exhaust gas components on the atmosphere [32, 37]. New measurement and numerical methods of obtained research results have also been proposed [10, 39].

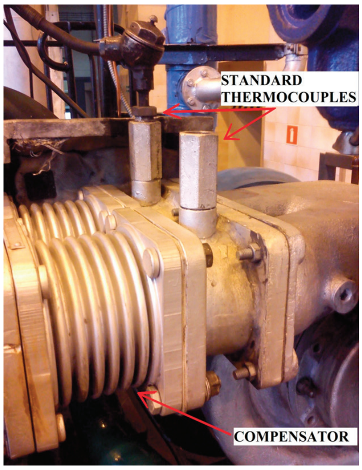
The main research aims of author included the reconstruction of the quick-changing temperature of engine exhaust gases with mathematical modelling of the heat exchange in the thermocouple and the identification of known and recognizable defects in the marine diesel engine that have a direct or an indirect influence on the course of the combustion process. The utilitarian aim of the research was to develop a methodology for diagnostic tests of a marine engine in operating conditions based on measurements of the quick-changing temperature of exhaust gases.

QUICK-CHANGING EXHAUST GAS TEMPERATURE AS A DIAGNOSTIC PARAMETER

During measurements of the quick-changing exhaust gas temperature, there are many problems that must be considered and partially or completely eliminated in order to obtain as much diagnostic information from this parameter as possible. These problems include primarily the inertia of the thermocouple, the dependence of the lifetime on the design and diameter of the thermocouple, the method of mounting the sensor and its heating [24, 25]. The most difficult from a metrological point of view is the selection of the place and mounting method for the thermocouple for the measurement of quick-changing temperatures of the exhaust gas when a ship engine working in real operating conditions (in a ship engine room) is considered. The best solution for this situation is to adapt a standard thermocouple for an engine measurement system (Fig. 2). The measurement of the quick-changing exhaust gas temperature at the standard measurement location seems to be the most advantageous solution, since the diagnostician does not interfere with the design of the engine working spaces. However, the following factors must be considered:

- delay of the signal in relation to the temperature signal recorded inside the cylinder and fluctuation of the recorded signals;
- resistance to flow in the exhaust gas channel, which depends on its constructional form and technical condition of the internal surface;
- wave phenomena taking place in the channel (interference and reflection of the pressure waves coming from the other cylinders cooperating with the channel supplying the turbocharger) [9]; and
- adiabatic compression of the gas column in front of the next pulses of exhaust gas leaving the engine cylinders [9].

a)



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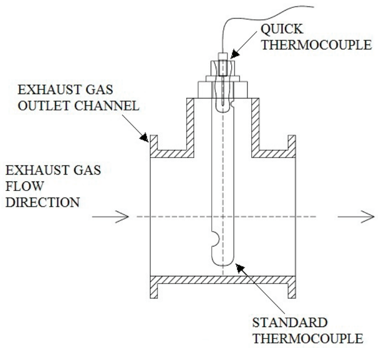


Fig. 2: (a) General view of exhaust gas ducts supplying a marine diesel engine turbocharger in a pulse system with a place for mounting standard thermocouples and (b) schematic diagram of adaptation of a standard thermocouple by mounting a thermocouple for high-speed measurements

Among many functional systems of marine diesel engines, the authors have pointed out the following as the most frequently damaged: the fuel supply system and working medium exchange system [9, 35]. Other types of damage are associated with the piston-crank system or bearings and disturbances in the combustion process, which may manifest themselves as a decrease in the compression ratio ε [3, 18, 36].

During diagnostic testing of an engine in a steady state of operation, the values of the control parameters, namely, the input and output, are recorded. For the purposes of diagnostic inference, those of the output parameters are selected because they react more strongly to changes in the values of the parameters of the construction structure than to changes in the values of the input parameters that force the implemented work process. In this way, a set of diagnostic parameters is obtained that is independent and complete. The basic condition for the selection of suitable diagnostic parameters is a much higher sensitivity of the output parameter with respect to the structure parameter than its sensitivity with respect to the input parameter. Comparing the sensitivities of multiple control parameters that are given in different units of measurement forces the need to assume relative values of input, output and structure parameters for this purpose [8].

There are many methods of assessing the significance of the influence of changes in structure parameters on the analysed physical process and the values of the output (diagnostic) parameters. These include the concept known from classical mathematical analysis, which is the distance between functions, information entropy derived from qualitative information theory, and non-parametric and parametric statistical tests [9, 11, 13, 17, 30]. The diesel engine control parameter, i.e., the quick-changing exhaust gas temperature, can be a valuable source of diagnostic information provided that the condition assessment methodology based on this parameter is properly prepared [19]. To achieve this aim, it is important to select an appropriate measurement technique, tools for mathematical processing and methods of statistical and content-related analysis of the obtained results [14, 15].

F – STATISTICS AS A TOOL FOR IMPACT SIGNIFICANCE ANALYSIS

When assessing the influence of one input parameter of the engine (constructional structure) on one output parameter (quick-changing temperature of the exhaust gas), a program for a static and randomized complete experiment was developed that used the Fisher-Snedecor distribution for the analysis of the F statistic, since the conditions for the application of one-sided parametric tests were met [11, 23]. The null hypothesis, which is formulated in advance and verified with statistical tests, assumes that there is no influence of the input factor on the output factor. The influence of an input factor is considered significant when the calculated value of the applied statistic is equal to, or greater than, the critical value that is given in tables for the applied value of the significance level and number of degrees of freedom. In this study, it was assumed in advance that the results of the measurements of all control parameters can be modeled as random variables with a normal distribution, where the specified variance is a measure of the dispersion around the mean value. It was also assumed that the variances of the random variables are equal or close in value, and that the parametric tests for the variance had a one-sided critical area.

For the one-factor analysis (randomised complete plan), an assessment was made of the significance of the influence of the input factor, which was the structure parameter, over a specified range of variability according to the regulator characteristics on the determined diagnostic parameter (output factor).

The test (calculated) value of F statistic for the Fisher - Snedecor distribution was determined (in this case for specific enthalpy of exhaust gases as an output factor) based on the following relation:

$$F = \frac{\sum_{i=1}^{p} n_i \cdot (\overline{h}_i - \overline{h})^2 \cdot (n-p)}{[\sum_{i=1}^{p}\sum_{j=1}^{q}(h_{ij}-\overline{h})^2 - \sum_{i=1}^{p} n_i \cdot (\overline{h}_i - \overline{h})^2] \cdot (p-1)} \quad (1)$$

where ni is the number of specific enthalpy measurements at a given level, n is the total number of measurements, $\overline{h}_i$ is the average specific enthalpy of the results of the measurements in the i-th row, $\overline{h}$ is the average specific enthalpy of the results of all measurements, hij is the value of j-th specific enthalpy at level I, and p is the number of levels of variation of the input factor

As a complement to the statistical analysis, ΔF values, which are the difference between the value of the Fobl statistic calculated for the input factor under research and the critical value Fkr for the assumed values of the numerator and denominator degrees of freedom and the significance level. In the case of a single classification, the F statistic is calculated as the ratio of the variance of the input quantity to the variance characterizing the measurement imprecision. Thus, the larger the value of ΔF is, the greater the strength of the influence of the input factor on the output parameter under analysis.

STAGES OF ANALYSIS

To obtain the value of the Fobl statistic and the difference ΔF it was necessary to proceed according to the developed scheme [23]. The recorded signal in the first step was subjected to mathematical processing (removal of fluctuations from the measurement network by the method of sum of least squares). It was then determined the response of the thermocouple to the sinusoidal forced gas temperature; i.e., the phase shift and amplitude of temperature changes recorded by the thermocouple in relation to the forced, real gas temperature changes [24, 25]. Diagnostic measures were determined from the obtained real and interference-free quick-changing exhaust gas temperature. Due to the application of the randomised complete plan, irrelevant input quantities were extracted and eliminated from the test object function, and a substantive justification was performed. The final step was the implementation of the block randomised plan, and the statistical and substantive analysis will be presented as a continuation of this paper.

DIAGNOSTIC MEASURES

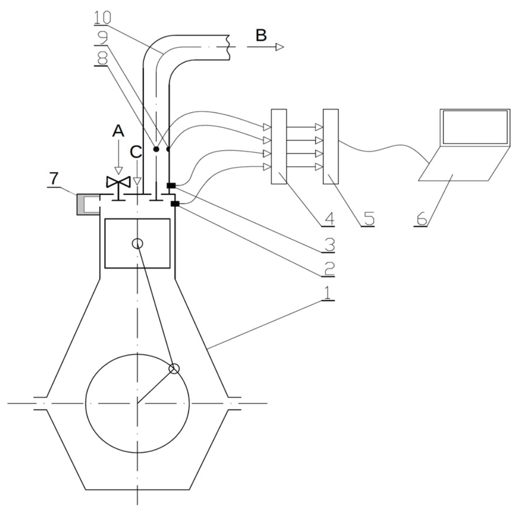
The results of the laboratory tests involved the exhaust gas temperature variation for a single engine operation cycle. Three different measurement signal standards were analysed, determined based on measurements and analysis of the quasi-periodic signal, i.e., the quick-changing temperature of exhaust gases in the exhaust duct of a marine diesel engine, which was determined from the signal subjected to earlier mathematical treatment [7, 16, 24, 28].

The average peak-to-peak value of the quick-changing temperature of exhaust gases ΔTśr was determined as the difference between the maximum and minimum temperature values for particular engine operation cycles. The value of specific enthalpy of exhaust gas hśr was determined by integrating the quick-changing temperature of the exhaust gas within the limits determined by the values of the angle of rotation of the engine crankshaft for one cycle of work with a known value of the specific heat of the exhaust gas cp, which was calculated from stoichiometric equations for their average temperature. The cp value was determined based on fuel composition and over-air ratio measurements recorded for each operating condition of the marine diesel engine. The knowledge of the rate of increase and decrease in the exhaust gas temperature $\Delta T/\Delta\tau\uparrow$ allowed the determination of the dynamics of the observed thermo-fluid process. Because the real signal after amplitude-phase correction was analysed is a sinusoidal waveform, the values of the rate of increase and decrease in exhaust temperature were the same. The exhaust gas temperature increase (decrease) rate was determined as a ratio of two differences: the difference between maximum and minimum values of exhaust gas temperature within one engine operation cycle in [K] and the difference between the time when the exhaust gas temperature within one engine operation cycle reached its maximum and minimum values [s]. The mentioned diagnostic measures are described in more detail in the publication [26].

EXPERIMENTAL RESEARCH ON A REAL OBJECT

The empirical research was carried out on a laboratory test stand comprising a single-cylinder, type D10 four-stroke Farymann Diesel marine diesel engine (Fig. 3) located in the Laboratory of Marine Power Plants Department, Faculty of Mechanical Engineering and Ship Technology, Gdansk University of Technology. The basic technical data of the engine are: nominal power of 6 kW, nominal speed of 1500 min-1, nominal torque of 38 Nm, cylinder diameter of 90 mm, piston stroke of 120 mm, compression ratio of 22:1, and displacement of 765 cm3. Table 1 lists the measured control parameters and the measuring equipment used during the test.

a)



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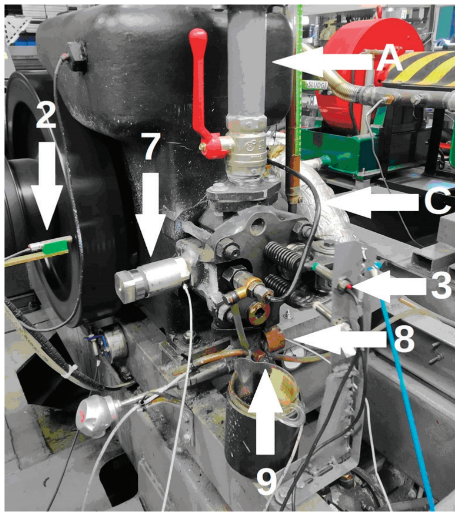

Fig. 3. (a) Schematic diagram and (b) view of the laboratory stand with locations of the measuring sensors: 1 is the Farymann Diesel engine type D10, 2 is the engine speed and TDC sensor, 3 is the exhaust valve opening sensor, 4 is the A/C converter, 5 is the recorder, 6 is the analysis program, 7 is the structural element enlarging the combustion chamber volume, 8 is the exhaust gas pressure sensor, 9 is the water cooled thermocouple, 10 is the exhaust gas outlet channel, A is the inlet air, B is the exhaust gas, and C is the supply fuel

Table 1: Control parameters recorded in the laboratory bench for the type D10 Farymann Diesel engine

Item	Parameter	Measuring device	unit	Measurement range
1	Exhaust gas temperature – T_{sp2}	Grounded type K thermocouple with the junction of external diameter of 0.5 mm, made from inconel	°C	0–1000
2	Exhaust gas pressure in the exhaust channel – p_{sp}	Optical pressure sensor – Optrand C12296	V	0–689475.73 Pa (0–100 psi), sensitivity $6.01\cdot10^{-8}$ V/Pa (41.43 mV/psi)
3	Engine speed (angular position °C.A.) – n Top dead centre – TDC	Induction engine speed sensor and TDC sensor	min^{-1}	0–3000
4	Load Current of the generator (armature) – I_{tw}	Electric current meter	A	0–15
5	Voltage at the armature terminals– U_{tw}	Voltmeter	V	0–250
6	Exhaust valve opening signal	Gap type opto-isolator with a comparator LM393	V mm	0–5 10 (gap)

A multifunctional DT-9805 measuring and recording module from the Data Translation company was used to record the control parameters. Matlab software was applied to record the registered data in the programming language. The measurements were carried out for 3 operating points according to the regulator characteristics due to the limited possibilities of the load control system and the control of the fuel dose feeding the tested engine. During the test, a constant rotational speed for the crankshaft was maintained in the range from 1442-1444 rpm for the following engine loads: Pobc1=432W, Pobc2=768W, and Pobc3=1200W. The sampling frequency was approximately 7000 Hz. The presented test results are the average of 90 consecutive measurements recorded under the same engine operating conditions determined by its load, crankshaft rotational speed and ambient parameters. During the tests, the engine was burning MGO marine fuel. The main objective of the empirical investigations was to establish the diagnostic value of the quick-changing temperature of the exhaust gas of a piston engine; therefore, it was necessary to determine its sensitivity to changes in the parameters of its constructional structure. Accordingly, the input variables were the structure parameters listed below.

Firstly, the active cross-sectional area of the inlet air channel Adol changed its value relative to the reference state, which was understood as full opening of the control valve. This simulated the loss of permeability of the filter baffle. The value of the active cross-sectional area of the intake air duct flow was changed for 3 ranges (100% - 804 mm2, 75% - 603 mm2, and 50% - 401 mm2) [27]. The injector opening pressure pwtr controlled by the spring relaxation in the injector was chosen as the second input parameter for the construction structure. In the tested engine, an injector with shims with a thickness δwtr equal to 1.3+1 mm was installed, which resulted in a fuel injector opening pressure value of about 12 MPa (reference state value). During the test for condition 2, shims with a thickness of 1.3+0.5 mm were installed in the injector, which caused the injector opening pressure to decrease to 10 MPa, simulating the failure of the fuel injection system. In the third step, changes were made to the structure parameter of combustion chamber volume, which was reflected in the values of engine compression ratio ε. The reference value for the tested engine was εREF= ε1=22:1, while the reduced value was ε2=21:1 due to the design limitations of the single cylinder engine, which was very sensitive to even the smallest changes in the values of the structure parameters. A decrease in the compression ratio was realised by the application of an additional structural element, increasing the volume of combustion chamber by ΔVk=0,125·10-5 m3. The original (reference) volume of the combustion chamber was Vk1=3,787·10-5 m3, and displacement volume was Vs=79,5·10-5 m3. Before starting the tests, a preliminary experiment was conducted to evaluate the effect of the engine load P on the quick-changing exhaust gas temperature (P was treated as an input parameter).

RESULTS

Mathematical and statistical analyses were used to calculate the values of the defined diagnostic measures ($h_{śr}$, $\Delta T_{śr}$, $(\Delta T/\Delta\tau\uparrow)_{śr}$) during one engine cycle. Values for the F_{obl} statistic were determined for the input parameters, which were the variable structure parameters (A_{dol}, p_{wtr}, ε). The following null hypotheses were posed to determine the value of the F_{obl} statistic H_{0i}:

Table 2. The value of the statistics F_{obl} and ($\Delta F=F_{obl}-F_{kr}$) for variable values of the analysed structure parameter:(a) active intake air flow area, (b) injector opening pressure, and (c) compression ratio

a)

Point according to the regulator characteristics	$h_{śr}$, kJ/kg	$\Delta T_{śr}$, °C	$(\Delta T/\Delta\tau\uparrow)_{śr}$, K/s
P_1 (432 W, 5.1 A, and 72 V)	157.10 (153.42)	30.44 (26.76)	30.42 (26.73)
P_2 (768 W, 6.8 A, and 96 V)	119.39 (115.70)	14.93 (11.24)	14.93 (11.25)
P_3 (1200 W, 8.5 A, and 120 V)	357.14 (353.45)	16.24 (12.55)	16.27 (12.59)

b)

Point according to the regulator characteristics	$h_{śr}$, kJ/kg	$\Delta T_{śr}$, °C	$(\Delta T/\Delta\tau\uparrow)_{śr}$, K/s
P_1 (432 W, 5.1 A, and 72 V)	0.81 (-5.18)	225.60 (219.61)	70.53 (64.55)
P_2 (768 W, 6.8 A, and 96 V)	5.72 (-0.27)	85.06 (79.08)	85.23 (79.24)
P_3 (1200 W, 8.5 A, and 120 V)	15.05 (9.06)	263.41 (257.43)	263.88 (257.89)

c)

Point according to the regulator characteristics	$h_{śr}$, kJ/kg	$\Delta T_{śr}$, °C	$(\Delta T/\Delta\tau\uparrow)_{śr}$, K/s
P_1 (432 W, 5.1 A, and 72 V)	52.34 (46.35)	70.22 (64.23)	70.32 (64.34)
P_2 (768 W, 6.8 A, and 96 V)	22.12 (16.13)	143.85 (137.86)	144.13 (138.14)
P_3 (1200 W, 8.5 A, and 120 V)	11.99 (6.00)	83.84 (77.85)	83.98 (77.99)

H_{01}: the value of the analysed structure parameter has no influence on the value of the specific enthalpy of the exhaust gas stream averaged over one engine operating cycle ($S_{II}^2 = S_I^2$).

H_{02}: the value of the analysed structure parameter has no influence on the peak-to-peak value of the exhaust gas stream temperature within one engine operating cycle ($S_{II}^2 = S_I^2$).

H_{03}: the value of the analysed structure parameter has no influence on the value of the rate of increase and decrease in the exhaust gas temperature within one engine operating cycle ($S_{II}^2 = S_I^2$).

Based on the numerical data and the adopted significance level α=0.05 and the assumption of the right-side critical area, the values of all three diagnostic measures were determined for the exhaust gas stream within one engine cycle for each measurement point (P_i), the variable structure parameter, and the number of degrees of freedom for the numerator and denominator f_1 and f_2. Then, the critical value of the statistic $F_{kr}=F(\alpha; f_1; f_2)$ was read from the statistical tables [10] and the values of F_{obl} were determined, which are presented in Table 2. When the condition $F_{obl}>F_{kr}$ was met, the null hypothesis was rejected. In further diagnostic tests, it was assumed that in the considered range of variation of the engine load and for values of the structural parameter in analysed engine, it (the structural parameter) had a significant influence on the diagnostic measures determined within one working cycle of the marine piston engine (positive values of ΔF in Table 2 marked with blue colour).

To evaluate the significance of the influence of the structure parameters in the background of the variable load of the marine diesel engine, the characteristic curves presenting the diagnostic measures ($h_{śr}$, $\Delta T_{śr}$, ΔT/Δτ↑) determined based on the variation of the quick-changing exhaust gas temperature as a function of the load of the tested engine were determined (Fig. 4). The measures of stratification of these characteristics are the analysed structure parameters (A_{dol}, p_{wtr}, ε).

Based on the results of the statistical analysis (Table 2) and the prepared variability characteristics of the determined diagnostic measures in the background of the engine load (Fig. 4), the following significant conclusions were drawn for the considered range of load variability and engine structure parameters.

1. Reducing the active area of the inlet air flow A_{dol} significantly affected all determined diagnostic measures (Tab. 2a). The strongest effect of this structure parameter occurred in the case of exhaust gas specific enthalpy (highest ΔF).
2. A reduced injector opening pressure p_{wtr} significantly improved the values of the peak-to-peak exhaust gas temperature and rate of increase (decrease) of the exhaust gas temperature for all analysed engine loads. However, the influence of this structure parameter on the exhaust gas specific enthalpy was significant only at the point of maximum engine load (Tab. 2b). The effect of injector opening pressure on the exhaust gas specific enthalpy, meanwhile, was much smaller (ΔF≈9) than for the other two measures, where the value of ΔF was of the order of tens or even hundreds.
3. The effect of the reduced compression ratio ε was significant for all diagnostic measures determined and for the whole range of engine load variation considered (Tab. 2c).
4. For the specific enthalpy of exhaust gas $h_{śr}$, the reduced compression ratio increased the value of this diagnostic measure. On the other hand, other changes in the structure parameters (decrease in the active air flow area and decrease in fuel injection pressure) relative to the reference state resulted in a decrease in the value of this diagnostic measure ($h_{śr}$) (Fig. 4a).
5. In the case of the average peak-to-peak value and the rate of increase (decrease) of the exhaust gas temperature, all the introduced changes in the input parameters of

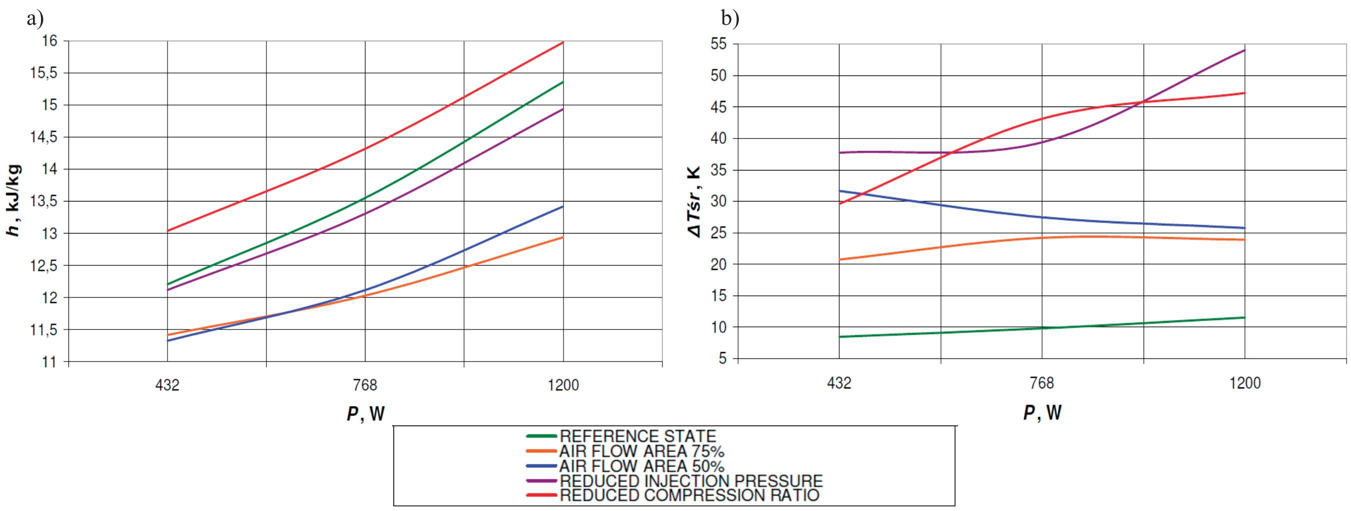

Fig. 4 Characteristics of variation of the determined diagnostic measures within one work cycle as a function of the load for the reference and partial operational states: (a) specific enthalpy of exhaust gas and (b) average value of peak-to-peak temperature of exhaust gas where the reference state is A_{dol}=100%, p_{wtr}=12 MPa, ε=22:1, the air intake is 75% and 50% relative to reference, the injector opening pressure was reduced to 10 MPa, and compression ratio was reduced to 21:1

the structure caused an increase in these diagnostic measures, which should be interpreted as an increase in the dynamics of the course of the quick-changing exhaust gas temperature (Fig. 4b).

FINAL REMARKS AND CONCLUSIONS

The quick-changing exhaust temperature in the outlet channel of the marine diesel engine can be a valuable source of diagnostic information about the condition of structural elements enclosing the combustion chamber, the fuel system and the inlet air channel. However, it is not always possible to measure these parameters in a combustion chamber primarily because of the low controllability of a serial engine. In such a case, a diagnostic alternative is the measurement of the temperature in the exhaust gas channel with an appropriate consideration of the phenomena occurring there that have an impact on the values of the determined diagnostic parameters. While measurements of the pressure in the exhaust gas duct are also not always possible, measurements of the static exhaust gas temperature are realised as a standard procedure. Therefore, by using a suitably "fast" thermocouple instead of a standard one during engine testing, much more detailed diagnostic information can be obtained. It is possible to develop a diagnosis methodology based on the quick-changing temperature.

In future work, a two-factor analysis is planned according to a randomised block plan. This will allow an evaluation of the influence of two input values. In the analysed case, this is the evaluation of the influence of structure parameters in the background of variable load. The final step of the statistical analysis of the measurement results obtained by using the complete and block randomised plans will be an assessment of the merit.

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CONTACT WITH THE AUTHOR

Patrycja Puzdrowska
e-mail: patpuzdr@pg.edu.pl

Gdańsk University of Technology
Narutowicza 11/12
80-233 Gdańsk
Poland