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Engine Room Simulators
Симулатори на машинното отделение

TWO STROKE DUAL FUEL ENGINE PERFORMANCE ANALYSIS ON LIQUID AND GAS FUEL MODE RELATED TO THE NEW TRAINING DEMANDS FOR MARINE ENGINEERS

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Abstract. The present publication shows the results of the planned experiment with a two-stroke dual fuel engine with low pressure of the fuel gas supply in simulated environment on the Wartsila Voyage technological simulator available in Nikola Vaptsarov Naval Academy. The aim of the publication is to facilitate the training process for the specific features in the two different modes of operation of the dual fuel engines on liquid and gas fuel in the context of the turbocharging system condition. The outcomes of the training need to cover the minimum knowledge for safe operation of the ship power plant by the trainees. The subject of the research is a low-speed two-stroke dual fuel engine WIN GD 6X72 DF. The plan of the experiment includes variation in the degree of fouling of the turbine and compressor side of the engine turbocharger ABB A180L and the associated deviations in the engine performance parameters. The variety of performance parameters selected for examination allows the conclusion of several outcomes with technical and educational benefits for the training process. They could be used in the lectures and exercises carried out with the under- and post-graduates in the marine engineering specialty.

Keywords: education and training; engine simulator; WIN GD 6X72 DF; turbocharger fouling; engine performance deviation

1. Introduction

The dual fuel engine application in the marine industry gains new fields with the new buildings and thus the demand on the knowledge about its technology increases. It is a relatively new technology for the marine industry which relies on a certain restricted number of engineer officers worldwide. Respecting the knowledge of the experienced marine engineers, it is clear that the LNG combustion technology in the internal combustion engines has significant differences with the well-known Diesel engine technology. In the publication, the aim of the authors is to state the differences in the basic parameters of the engine operation on liquid and gas fuel mode with the engine condition changes due to normal wear and fouling during operation for the training purposes in the Nikola Vaptsarov Naval Academy. For the above mentioned, a controlled experiment was carried out in the simulated environment of the Wartsila Voyage simulator with a modeled subject engine WIN GD 6X72 DF – two-stroke marine dual fuel engine working on Otto cycle in gas fuel mode and on conventional Diesel cycle in liquid mode. The turbocharger of the subject engine is ABB A180L – a modern concept turbocharger with internal slide bearings, centrifugal compressor, and axial turbine wheel. The differences in both operations related to the turbocharging system setup and its influence on the operation of the engine are critical for understanding by the technical operators. The gas-operated engine keeps proper air-gas-fuel ratio for normal safe operation without pre-combustion issues and low NOx emissions. The role of the turbocharging system is critical for the proper supply of a specific amount of air for this ratio, linked to the engine power demand. The normal deterioration of the turbocharger condition would lead to the inability to control the engine operation in gas mode. This could be problematic for the normal environmentally friendly operation of the ship driven by the engine (Popov 2022).

The process of training of new marine specialists or experienced ones requires the set-up of a database for studying the problems of the specific features (Vasilev 2022a). There are numerous cases of engine damage occurring due to a lack of proper diagnostic processes of their operation (Popov 2022). The available information is not sufficient for a decent understanding of the processes and nowadays it has opened the field for various validated data to be analyzed (Vasilev 2022b). The authors of the publication focus on the realistic changes in the condition of the turbocharger to an extent related to the normal processes seen in the marine field.

2. The experiment

Two-factor analysis has been performed within the simulated environment. The two factors selected are the technical condition of the turbine and the compressor's side of the turbocharger. These two factors are critical for the proper condition evaluation of the turbocharger and are considered in the course of the marine turbomachinery educational program at Nikola Vaptsarov Naval Academy in the Marine engineering specialty of the bachelor's and master's degrees. The new data for the different behavior of the turbocharger in case of the use of different types of fuels would be used as an added knowledge to the existing one in the educational program and would give the advantage to the future engineers to recognize the problematic condition of the turbochargers under their supervision. The mathematical models intended to be achieved would be used as presented 3D diagrams in the lectures presented on this matter. Further in the practical exercises during the turbochargers study, the data would be used as reference to evaluate the present condition of the machinery, considering different initial conditions in the environment of engine room simulator, i.e. as new or deteriorated ones.

The advantage of the use of a simulator for the experiment is not only linked to the availability of the real test object and the cost of such an experiment but also to the ease of data collection and the correct registration of variation factor values. The the turbine and compressor's side were chosen fouling of the turbocharger in range from clean and fit condition to both sides to fouled condition of both sides evaluated as 20% maximum each. The plan of the experiment included different combinations of both factors' levels changing with steps of 5%. The load of the engine was kept constant at 80% during the tests. The experiment results for the considered operational factors linked to the turbocharger condition were the compression pressure (Pc), the maximum combustion pressure in the cylinder (Pmax) and the temperature of the exhaust gases from the cylinders (Tgas). The considered operational factors are the basic ones in the processes of studying the mechanical and the thermal stresses experienced by any internal combustion engine. The results obtained in the experiment are shown in Table 1.

It was decided to maintain a constant load of the engine achieved by the electronic governor. Due to the differences of the processes on diesel and gas fuel mode in the case of low pressure gas admission as it is with the experiment, we can assume that the critical capacities of the fluids processed by the engine are similar for achievement of the power demand and there are no significant deviations in the condition of the operation of the engine in respect to the equal condition of the engine load during the entire experiment.

Table 1. Experiment results[1]

Compressor fouling	Turbine fouling	Engine Compression Pressure	Engine Maximum Pressure	Exhaust Gas Temperature	Engine Compression Pressure	Engine Maximum Pressure	Exhaust Gas Temperature
%	%	bar	bar	° C	bar	bar	° C
		Gas fuel mode (Otto cycle)			Liquid fuel mode (Diesel cycle)		
5	0	92.0	186.1	362.5	112.5	120.3	429.5
0	5	85.2	174.1	362.5	112.4	120.2	430.5
10	0	90.1	184.0	354.4	112.6	120.3	430.5
0	10	83.5	172.3	367.5	108.0	116.4	387.4
15	0	89.7	183.5	354.4	112.5	120.3	431.5
0	15	82.1	185.3	374.5	112.7	120.4	431.5
20	0	84.9	173.8	366.4	112.5	120.3	432.5
0	20	80.6	186.2	378.5	111.8	119.6	432.5
5	5	87.8	181.7	362.4	112.2	119.6	436.4
10	5	90.2	184.4	366.4	112.6	119.9	441.5
10	10	90.4	184.9	377.4	112.5	119.9	436.5

15	10	90.1	184.4	378.5	112.3	119.7	437.5
15	15	82.8	174.4	385.4	112.4	119.7	438.5
20	15	81.9	173.0	384.5	112.5	119.9	440.5
20	20	80.1	184.9	388.5	111.2	118.7	443.4

Although differences can be seen in the same parameters of the engine for the different modes of operation, they can be explained by the different set up by the engine control system. Compression pressure in gas mode is lower than this in liquid mode. Maximum pressure on the gas is significantly higher than this in liquid mode and there are differences in the exhaust gas temperatures in both modes – higher on liquid mode.

The processes observed could be explained by the following mechanism. The compression pressure is linked to the amount of air admitted to the cylinder. In gas mode, we have control of the air-gas fuel ratio. For adjustment of the ratio, the turbocharger is controlled to reduce power of the turbine by-passing part of the exhaust gas stack to the exhaust duct. In that way, the power transmitted to the compressor is reduced and the compressor capacity is reduced. The reduced amount of air admitted to the cylinders leads to reduced compression pressure (Pc). The explained process is not performed on Diesel mode of operation. Then we have direct passage of the gases to the turbine and the entire gas energy is converted in the turbocharger, so the amount of air is normally higher to the cylinders.

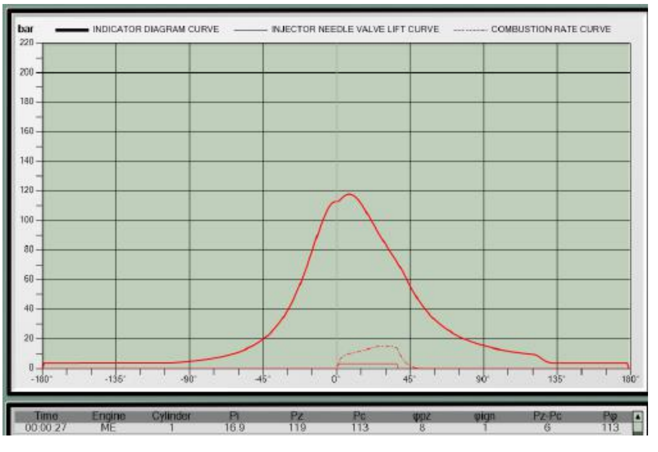

Figure 1. Engine performance curve – Otto cycle[2]

The maximum pressure (Pmax) differences come by the type of the combustion in both modes. In the Otto cycle, after the ignition occurs there is no control on the combustion intensity, due to the presence of the total amount of the combustion reagents in the combustion chamber, it is also dependent on the ignition timing fig (1).

In the Diesel cycle, there is a phase of controlled combustion while the combustion is performed, and liquid fuel is continuously sprayed into the cylinder. In that way, although the maximum pressure is not as high as in the other mode, the average pressure during the cycle is relatively higher fig (2). The last is linked also to the values of the exhaust temperature of the gases. The earlier fast-burning reaction leads to longer time for the gases cooling down while the cylinder expands in the Otto cycle which is not the same in the Diesel cycle with the continuous controlled combustion.

The comparison of the processes could be utilized as basic data analysis in the theoretical course for the DF engine supercharging system-specific features. Such problems would be incorporated in the further updates in the syllabi for marine engineers in the field of "New marine engine technology" in the bachelor's and master's programs.

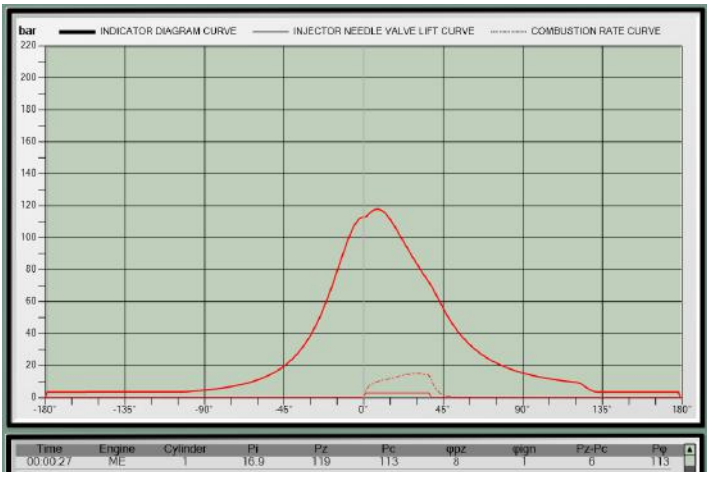

Figure 2. Engine performance curve – Diesel cycle[2]

3. Experiment result analysis

The experiment results are processed in a Matlab environment. Such an approach is commonly seen in scientific works and it is part of the routines of the authors. The regression analysis of the data has been performed. The high value of the R^2 of the obtained models shows that they can be used for the prediction of the behavior of the operating parameters within the range of the experiment in different ratios. The model's figures describing the dependencies of the parameters considered on the factors are shown. The outcome of that action can be used by the readers to perform similar tasks with available data subject of interest, especially for young engineering scientists.

3.1. The compression pressure (Pc) in Diesel mode has a bigger influence on the compressor's side condition of the turbocharger than the turbine side condition and it can be seen the extended influence on the range of 5 to 15 % fouling of the compressor (fig. 3). Here $R^2 = 1$ and it can be considered as a reliable mathematical model for prediction of the turbocharger performance in the range of the considered variables.

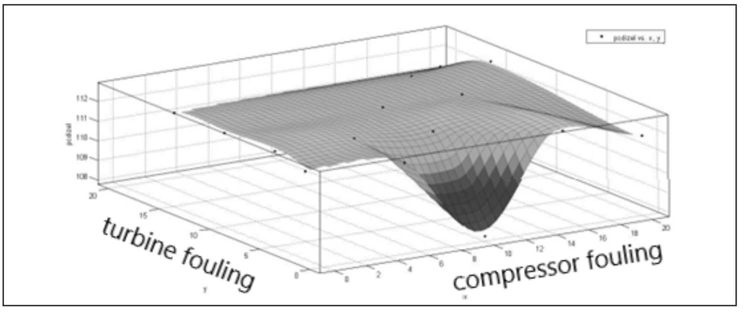

Figure 3. Compression pressure – Diesel cycle[3]

In gas fuel mode, the same operating parameter changes in different manner (fig. 4). Of the entire considered range, the fouling reduces the performance of Pc and it is multiplied in the area of both sides high extent of fouling. Due to the demand for air to be supplied to the cylinder and the control influence of the turbocharger on the air-gas fuel ratio on this mode, we have a wide range of reflection of the turbocharger condition on the engine performance. The value $R^2 = 1$ and again the model is reliable for prediction of the turbocharging system performance.

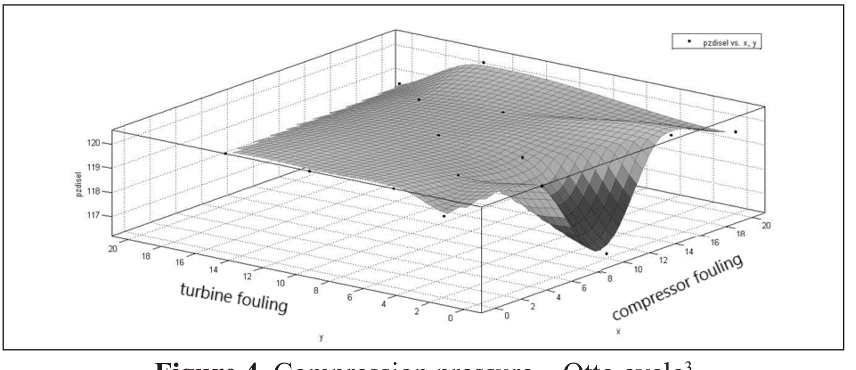

Figure 4. Compression pressure – Otto cycle[3]

3.2 The maximum combustion pressure (Pmax) has similar functional link to the turbocharger fouling in liquid and gas fuel mode as the compression pressure. As the processes of cylinder filling with fresh charge and the following combustion are strongly dependent on each other, we can confirm the influence of the turbocharger condition also on this parameter. We can state that the turbocharger needs to be in best condition to ensure normal, efficient and safe operation of the engine and vice versa. If the turbocharger is in poor condition, we can experience problems with inability to control the charge air amount, especially in gas fuel mode and thus to avoid the operation in gas fuel.

The model derived for combustion pressure Pmax on liquid fuel (fig. 5) has $R^2=1$ and it is reliable for predictions of the parameter in the range as it is similar for Pmax at gas fuel mode (fig.6) when we have also $R^2=1$.

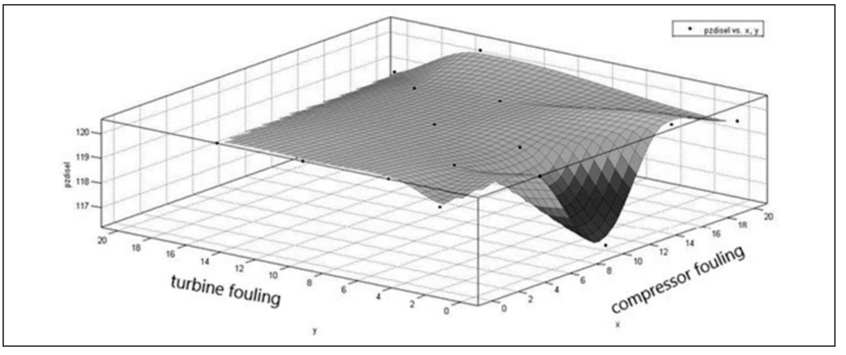

Figure 5. Maximum combustion pressure – Diesel cycle[3]

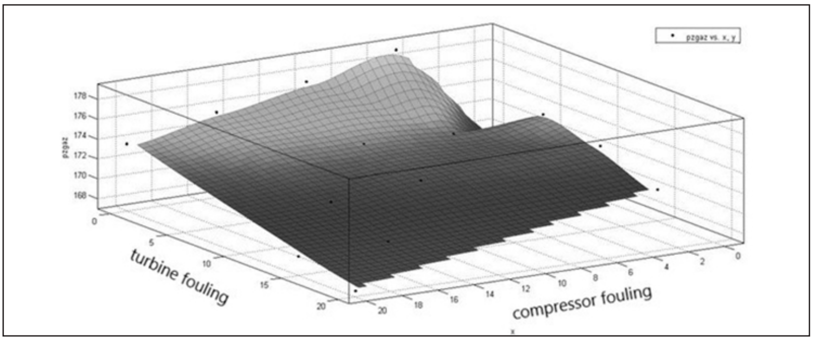

Figure 6. Maximum combustion pressure – Otto cycle[3]

3.3 The temperature of the exhaust gases (Tgas) in gas fuel mode linked to the experiment's results is shown on fig. (7) as this in liquid fuel mode is shown on fig. (8). The strong values of $R^2=1$ for both cases are to be considered. The models can be used for predictions and show in the case of gas fuel mode stronger link to the compressor side condition of the turbocharger. Due to the complex process of the combustion and the various factors which may lead to incomplete or late combustion, it can be seen that the shapes vary in the entire pattern of the three directions of the two-factor function.

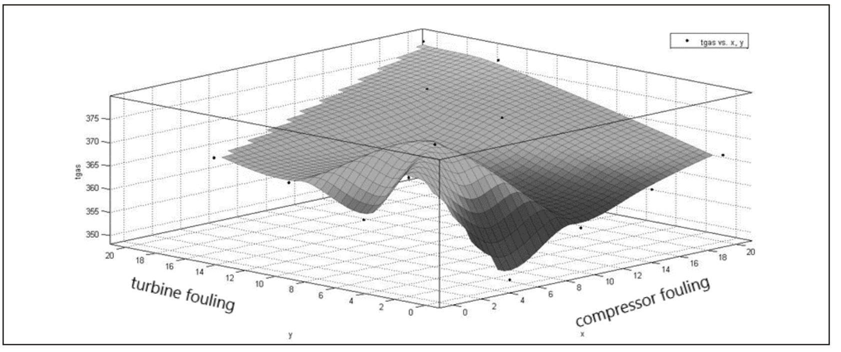

Figure 7. Exhaust gas temperature – Otto cycle[3]

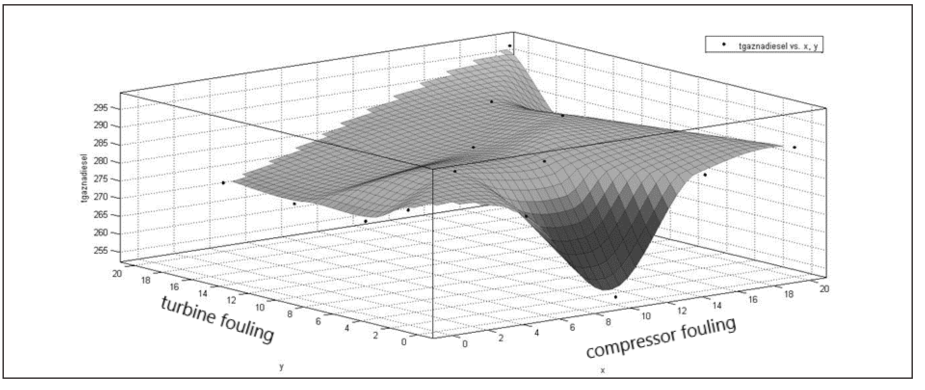

Figure 8. Exhaust gas temperature – Diesel cycle[3]

4. Conclusions

4.1. The aim of the publication to perform a planned experiment and to derive conclusions with an educational matter for modern dual-fuel engines has been accomplished and will be implemented in the training activities in Nikola Vaptsarov Naval Academy

4.2. Added new reliable models for prediction of the behavior of an engine with turbocharging system fouling components by using simulated environment for the theoretical preparation of the marine engineering students and post-graduates.

4.3. The publication contains ready-to-use data on the differences in the DF engines' operation on gas and liquid fuels with respect to the turbocharging system condition for references in the process of ship power plants diagnostics by the marine engineering students, researchers, and instructors.

4.4. The structure of the research could be used as a procedure for obtaining reliable mathematical models of a variety of physical systems by young scientists.

NOTES

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