

Roman Varbanets – Doctor of Technical Sciences, Professor, Head of the Department “Ship Power Plants and Technical Operation”, Odessa National Maritime University, Odesa, Ukraine, e-mail: [roman.varbanets@gmail.com](mailto:roman.varbanets@gmail.com), <http://orcid.org/0000-0001-6730-0380>

Dmytro Minchev – Doctor of Technical Sciences, Department “Ship Power Plants and Technical Operation”, Odessa National Maritime University, Odesa, Ukraine, e-mail: [misaidima@gmail.com](mailto:misaidima@gmail.com), <http://orcid.org/0000-0002-5960-3063>

Iryna Savelieva – Doctor of Economic Sciences, Professor, Department “Commerce in transport processes”, Odessa National Maritime University, Odesa, Ukraine, e-mail: [savirina@gmail.com](mailto:savirina@gmail.com), <https://orcid.org/0000-0002-6492-2130>

Andriy Rodionov – PhD student of the Department "Ship Power Plants and Technical Operation", Odessa National Maritime University, Odesa, Ukraine, e-mail: [andrei.a.rodionov@gmail.com](mailto:andrei.a.rodionov@gmail.com), <https://orcid.org/0009-0009-0038-4810>

Tetiana Mazur- PhD student, senior lecturer, “Department of ship power plants and systems”, Danube Institute of the National University "Odessa Maritime Academy", Izmail, Ukraine, e-mail: [mazur@dinuoma.com.ua](mailto:mazur@dinuoma.com.ua), <https://orcid.org/0009-0008-7816-145X>

Sviatoslav Psariuk – Superintendent of the Shipping Company “TRANSSHIP LTD”, Odesa, Ukraine, e-mail: [s.psar1224@gmail.com](mailto:s.psar1224@gmail.com), <https://orcid.org/0000-0002-9075-7546>

Vyacheslav Bondarenko – PhD student of the Department "Ship Power Plants and Technical Operation", Odessa National Maritime University, Odesa, Ukraine, e-mail: [reversdialogov@gmail.com](mailto:reversdialogov@gmail.com), <http://orcid.org/0000-0003-1956-0588>

Vladyslav Kyrnats – Candidate of Technical Sciences, Department “Ship Power Plants and Technical Operation”, Odessa National Maritime University, Odesa, Ukraine, e-mail: [kirnacsvlad@gmail.com](mailto:kirnacsvlad@gmail.com), <https://orcid.org/0000-0002-8308-7994>

## **IMPROVING DIAGNOSTIC METHODS FOR SHIP DIESEL ENGINES TO MEET INTERNATIONAL MARITIME ORGANIZATION (IMO) CARBON REDUCTION REQUIREMENTS**

### **Introduction**

The International Maritime Organization (IMO) has adopted a series of measures and strategies aimed at reducing greenhouse gas emissions and decarbonizing the maritime industry. The essence of the latest IMO requirements for decarbonizing marine engines is to reduce emissions of carbon dioxide (CO<sub>2</sub>) and other greenhouse gases.

In April 2018, the IMO adopted an initial strategy [1] to reduce greenhouse gas emissions from ships, which includes the following main objectives:

- reducing the amount of CO<sub>2</sub> emissions by at least 40% by 2030 and striving for 70% by 2050 compared to 2008 levels;

- reducing the total volume of greenhouse gas emissions from international shipping by at least 50% by 2050 compared to 2008 levels;
- aiming full decarbonization of maritime transport in this century [2].

To achieve these goals, the IMO proposes the use of various technological and operational measures, such as improving the energy efficiency of engines, using alternative energy sources such as liquefied natural gas (LNG) or hydrogen, and encouraging innovation in new technologies that enhance the efficiency of marine engines [1, 2].

Performance analysis and diagnostics of marine engines are essential for improving operational efficiency and decarbonization of marine engines. During performance analysis, key parameters such as MIP, IPower, Pmax, Pcomp, etc., are determined, analyzed, compared with sea trial data, and adjusted according to the chosen operational strategy.

Various diagnostic systems from different manufacturers are used for conducting performance analysis, such as Premet® XL by LEHMANN & MICHELS GmbH, Doctor Analysis by Icon Research Ltd., EPM-XPplus by IMES GmbH, MarPrime by Maridis GmbH, and D4.0H by Depas Lab. (ONMU) [3]. However, it should be noted that even the most advanced systems only determine a small portion of the parameters required for accurate and quality diagnosis of the critical components of the engine.

To expand the volume of analyzed information, a digital twin of the engine, such as Blitz-PRO [4], can be used. The digital twin is an advanced online model that is precisely tuned to the engine using data obtained from diagnostic systems. The digital twin allows for analyzing a wide range of parameters, thus enabling qualitative and reliable diagnosis of the technical condition of the engine components and monitoring emissions in accordance with the current requirements of the International Maritime Organization (IMO) [1, 2].

The safe operation of a vessel and its compliance with the latest International Maritime Organization (IMO) standards for decarbonization depend on the continuous and reliable operation of main and auxiliary engines. Such conditions can be ensured through periodic performance analysis and diagnostics of the engine's key components responsible for the quality of the working process. Performance analysis allows for optimizing the operation of cylinders, evenly distributing the load between them, and timely identifying dangerous trends in the engine's technical condition. Parameter analysis also helps reduce the overall vibration levels of the engines, achieve fuel consumption close to the rated values, and improve the overall energy efficiency of the vessel in accordance with IMO requirements.

Some defects can be identified through the analysis of indicator diagrams  $P(\text{°CA})$  and the main parameters of the working process calculated from them, such as Pmax, Pcomp, MIP, ignition angles, and fuel ignition delay periods. Examples of such defects can include deviations in MIP, Pmax, or end compression pressure, as well as increased ignition delay periods, and others.

The analysis of one of the most typical defects in cylinder operation - reduction in end compression pressure (Pcomp) - is associated with ambiguities. The reduction in Pcomp can be caused by several diverse reasons, such as wear of cylinder liners,

wear, breakage, and/or sticking of piston rings, valve leakage, or malfunctioning valves timing. All these causes will result in the same consequence - a decrease in the parameter  $P_{comp}$ , followed by  $P_{max}$  and  $MIP$  [3]. Thus, the true cause of the defect may remain uncertain.

Similarly, to the defect of decreased  $P_{comp}$ , some other defects that manifest on the  $P(^{\circ}CA)$  diagrams can be caused by various reasons. A typical example is malfunctions in the high-pressure fuel equipment operation. These defects often occur during continuous engine operation. For example, late combustion process, which is determined by the phases of fuel ignition points on the  $P(^{\circ}CA)$  diagram, can be a result of late fuel injection and/or wear of precision components in the high-pressure fuel equipment, leading to a decrease in fuel pressure before the injectors at the moment of injection. Therefore, determining operational defects based solely on the analysis of  $P(^{\circ}CA)$  diagrams may not be accurate.

Measurements and analysis of diagrams in the high-pressure fuel system before the injectors could provide comprehensive diagnostic information. However, such measurements do not comply with the strategy of non-destructive testing and cannot be carried out on marine engines in operational conditions due to the risk of fuel leaks when installing high-pressure sensors. Such measurements using non-standard devices are prohibited by most marine certification societies [5, 6].

An alternative to direct measurements is the use of vibration sensors on a magnetic platform. Such sensors can be quickly installed in a chosen location, reducing the overall measurement time and allowing for quasi-stationary engine operation conditions. Vibration diagrams and  $P(^{\circ}CA)$  diagrams should be recorded in parallel and analyzed together. The proposed method is suitable for analyzing defects in the high-pressure fuel equipment and the gas distribution mechanism. The use of magnetic vibration sensors fully complies with the modern strategy of non-destructive testing of marine engines.

The  $P(^{\circ}CA)$  diagrams and vibration diagrams, initially recorded as functions of time, are transformed into functions of crankshaft angle using an analytical algorithm for determining TDC:  $P(t, ms) \rightarrow P(^{\circ}CA)$  [3, 6].

### **Conclusion**

The analysis of emissions concentrations of  $CO_2$ ,  $NO$ , and soot during advanced marine diesel engine diagnostics using the D4.0HT system and Blitz-PRO online service showed that earlier fuel injection timing resulted in decreased  $CO_2$  specific emissions and soot, but increased concentration of nitrogen oxides ( $NO$ ). These findings suggest that careful consideration of fuel injection timing can influence emissions performance in accordance with current IMO requirements. Numerical analysis of these values can aid in the selection of an appropriate operational strategy that takes into account current IMO requirements, engine power, and fuel consumption rate, thereby optimizing engine performance and emissions control.

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Skonieczna Daria, University of Warmia and Mazury in Olsztyn, Faculty of Technical Sciences, Department of Vehicle and Machine Design and Operation, 10-957 Olsztyn, Poland

Vrublevskiy Oleksandr, prof. University of Warmia and Mazury in Olsztyn, Faculty of Technical Sciences, Department of Vehicle and Machine Design and Operation, 10-957 Olsztyn, Poland, [aleksander.wroblewski@uwm.edu.pl](mailto:aleksander.wroblewski@uwm.edu.pl)

Wesołowski Paweł, University of Warmia and Mazury in Olsztyn, Faculty of Technical Sciences, Department Electrotechnology, Power Industry and Automation, 10-957 Olsztyn, Poland

## **CORRELATION ANALYSIS OF PHYSICOCHEMICAL, RHEOLOGICAL AND TRIBOLOGICAL PROPERTIES OF USED LUBRICANTS**

### **Literature introduction**

Nowadays, with the development of technology, the importance of protecting machines from undesired effects is increasing. One such factor is friction, which results in tribological wear. Particularly exposed to this effect are kinematic pairs, between which there is a precise fit. It goes without saying, therefore, that a car engine, for example, must be provided with adequate lubrication to prevent it from wearing out too quickly. Various types of engine oils are used to protect the engine unit. Each is characterised by slightly different properties, so that the user can match the lubricant to the engine requirements as closely as possible.

The basic parameter determining the properties of lubricants is viscosity. The value of this parameter varies during the service process. Factors such as oxidation,