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DETERMINATION OF OPTIMAL OPERATING MODES OF MARINE DIESEL ENGINES EXHAUST GAS BYPASS SYSTEMS

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Abstract : A method for determining the optimal operating modes of marine diesel exhaust gas bypass systems is considered. The aim of this research was to determine the optimal volume of exhaust gas bypass for a marine medium-speed diesel engine, specifically the 6L20 Wartsila. Electronic engine control allows flexible adjustment of exhaust gas bypass process within a range of 0 to 10 % of the total volume of gases exiting the diesel cylinder. The use of exhaust gas bypass contributes to improving the environmental performance of marine medium-speed diesel engines, particularly in the operational load range of 55–85 %, where NO_x emissions in exhaust gases decrease by 3.5–15.4 %. The greatest reduction in NOx emissions occurs at loads of 75–85 %. The use of the exhaust gas bypass system is deemed effective for loads exceeding 75 %, with potential reductions in nitrogen oxide emissions ranging from 9.2 % to 15.4 %. For loads of 55–65 %, a reduction in nitrogen oxide emissions (3.3–5.6 %) is also observed, but with a simultaneous increase in specific fuel oil consumption (4.2–4.4 %). However, for certain bypass values, the diesel engine's thermal stress exceeds acceptable limits.
Key words : Efficiency, exhaust gas bypass, exhaust gas recirculation, fuel consumption optimization, marine diesel engine, NO_x emissions, operating mode, performance metrics, , scavenge air pressure, waste-gate, turbocharger bypass ratio.

1. INTRODUCTION

Currently, among the controlled parameters of marine diesel engines, much attention is paid to such an environmental indicator as the concentration of nitrogen oxides NO_X in exhaust gases (Figure 1) [1], [2]. This value is regulated by the requirements of international conventions, and its maintenance in the specified range is mandatory during the operation of ship power plants, both in the waters of the World Ocean and in the territorial waters of maritime countries.

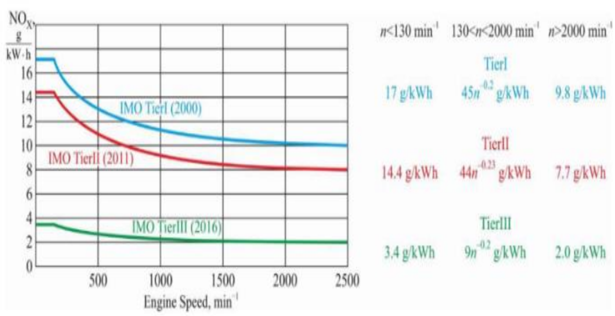

Figure 1 MARPOL-Annex VI-NOx in the exhaust gases of marine diesel engines [2]

The reduction of NO_X concentration in exhaust gases is achieved by:

• influencing the work process occurring in the cylinder;

• changing the design and operating parameters of high-pressure fuel equipment;

• introduction of reagents into exhaust gases during their passage through special reactors;

• by using the exhaust gas management system, which provides either Exhaust Gas Recirculation (EGR) or Exhaust Gas Waste-gate (EWG) [1].

Systems that provide recirculation of exhaust gases (EGR system), as a rule, are used for low-speed diesel engines. For marine medium-speed diesel engines, exhaust gas flow control can be carried out by bypassing them (EWG system). In this case, part of the exhaust gases of the diesel engine go directly to the gas exhaust line, bypassing the gas turbine of the gas turbocharger.

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At the same time, the frequency of rotation of the gas turbocharger, the pressure and the amount of air injected into the cylinder are reduced. Gases are bypassed with the help of a special valve, which allows you to direct part of the gases not to the gas turbocharger, but directly to the gas exhaust pipe. Currently, EWG systems are installed on marine medium-speed main and auxiliary diesel engines [2].

The use of the EGW system ensures a decrease in the concentration of NO_X in the exhaust gases, however (due to the deterioration of the combustion process) the power of the diesel engine decreases and the specific effective fuel consumption increases. In addition, the bypass of gases leads to an increase in the temperature stress of the diesel engine [3].

2. MATERIALS AND METHODS

The aim of this research was to determine the optimal volume of exhaust gas bypass for a marine medium-speed diesel engine, specifically the 6L20 Wartsila. When utilizing the EGW system, part of the exhaust gases is directed into the exhaust system bypassing the gas turbocharger. Electronic engine control allows flexible adjustment of this process within a range of 0 to 10 % of the total volume of gases exiting the diesel cylinder [4 - 6].

Research was conducted on three identical 6L20 Wartsila diesel engines with an electronic control system for fuel, air and gas distribution phases. The diesels were part of the ship's power plant as diesel generators, had the same engine life and were operated at equal loads. The EWG system is installed as an exhaust gas management system on these diesel engines. The Wartsila company recommends the use of this system primarily to limit the pressure of supercharged air and prevent surging phenomena during high loads and as an additional function – to reduce NO_X emissions. According to the project documentation, the EWG system provides the bypass of gases in the range of 0-10 % of their total volume. The schematic diagram of the 6L20 Wartsila marine diesel engine EWG system is shown in Figure 2 [7].

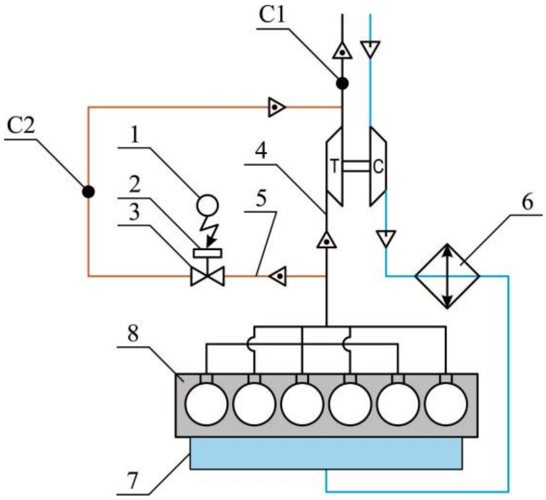

Figure 2 Schematic diagram of a marine medium-speed diesel engine 6L20 Wartsila with EWG exhaust gas management system [7]

Where:
1 – bypass valve position controller; 2 – pneumatic drive of the bypass valve; 3 – waste-gate valve; 4, 5 – outlet lines of the main and bypass flow of gases; 6 – charge air cooler; 7 – purge receiver; 8 – diesel cylinders; C1, C2 – gas flow control points;
T, C – gas turbine and air compressor of the turbocharger.

The air pumped in by the compressor is cooled in the charge air cooler 6 and enters the cylinders 8 through the purge receiver 7. The diesel engine implements a pulsed gas turbine supercharging system, in which the gas from the cylinders 8 is fed to the blades of the turbocharger through separate gas ducts. Depending on the position of the bypass valve 3 (the movement of which is carried out using a pneumatic drive 2 and regulated by the controller 1), the exhaust gases enter either the main line 4 or the bypass 5.

3. RESULTS AND DISSCUTIONS

The consumption of exhaust gases in the lines 4 and 5 was determined at points C_1 and C_2 using flowmeter. During the experiment, the NO_X concentration in the exhaust gases was determined using a gas analyzer at point C_1. The specific fuel oil consumption (SFOC) was determined with the help of ship measuring devices [2, 6].

The degree of gas bypass was calculated according to the formula [8]:

$$\delta_{EWG} = \frac{G_w}{G_\Sigma} \cdot 100\%, \quad (1)$$

where G_w – is the amount of exhaust gases that passed through the bypass valve, kg/s (measured at point C_2 using a flow meter);

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G_Σ – is the total amount of exhaust gases entering the gas exhaust line from the gas turbocharger with the bypass valve completely closed, kg/s (measured at point C1 using a flow meter).

The error in gas flow measurement did not exceed ±0.5 %, the error in measuring NO_X emission in exhaust gases did not exceed ±3.5 %, the error in measuring the specific effective fuel consumption did not exceed ±2.5 %.

The diesel, on which experimental studies were carried out, provided power to permanent groups of consumers. At the same time (depending on the studied modes) its power was 660 kW, 805 kW, 890 kW, 1010 kW, which corresponded to $0.55N_{enom}$, $0.67N_{enom}$, $0.74N_{enom}$, $0.83N_{enom}$. The error in power change did not exceed ±1.5 %.

The ship's power plant included three diesel engines of the same type, therefore, in the event of a change in the number of energy consumers and their power, the necessary load was redistributed to the diesel engines not involved in the experiment, while the diesel engine on which the research was carried out was operated at a constant load. In addition, during the diesel experiment, constant temperature conditions were maintained in the lubrication and cooling systems.

During the experiment, the diesel operated for 2.5–3 hours at a constant load and with an unchanged position of the bypass valve in each of the experimental modes.

To determine the degree of opening of the waste-gate valve, first, at point C1, the total gas flow G_Σ was determined, leaving the diesel cylinders and passing through the main gas flow line 4 (with fully closed valve 3).

After that, with the changed position of the waste-gate valve 3 at the point C_2, the gas flow G_w through the bypass line 5 was determined and the degree of gas bypass δ_{EWG} was calculated using formula (1).

The diesel cylinders exhaust gases average temperature – t_{eg}, which was measured by the ship's Doctor diagnostic system, was taken as a criterion for the thermal stress of the diesel engine.

The exhaust gases temperature is recommended by diesel manufacturing companies and scientific researchers as criteria for evaluating the course of the work process and the condition of high-pressure fuel equipment [9-10].

The results of the research are shown in Figure 3.

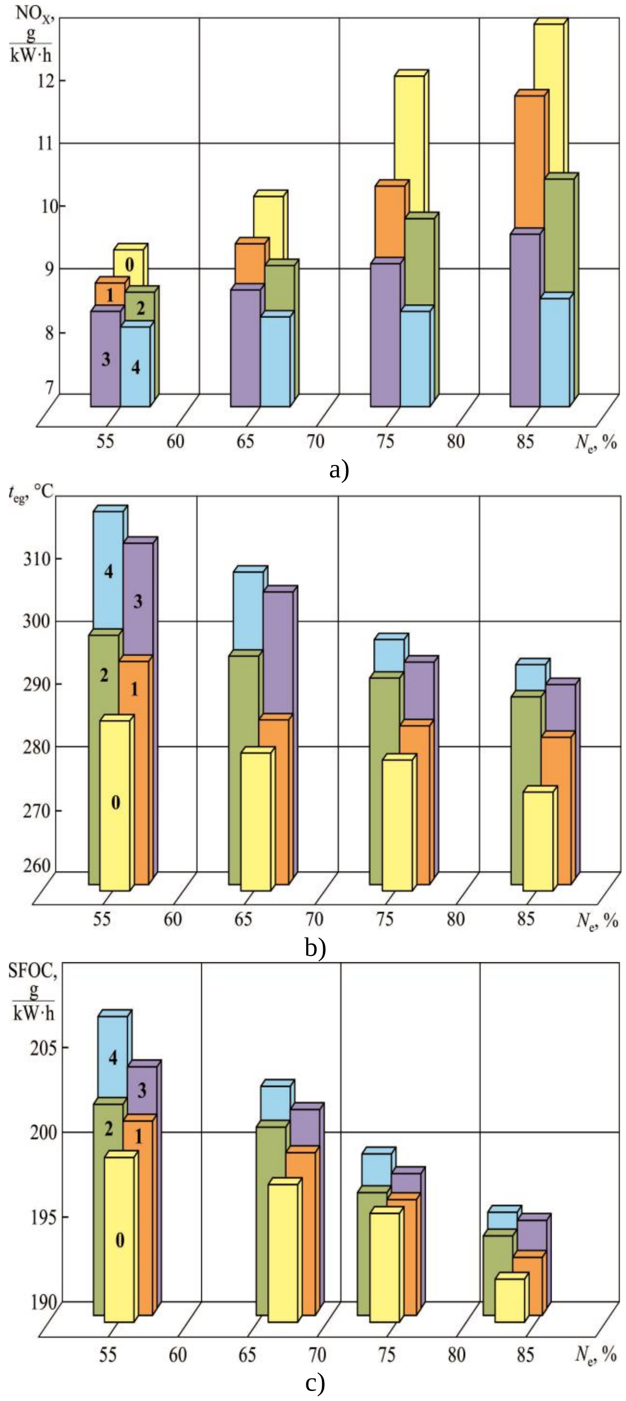

Figure 3 Change in a) NO_X emission, b) t_g, °C, and c) SFOC, for different loads N_e, %, marine diesel engine 6L20 Wartsila and different grades gas bypass [9]

δ_{EWG}:
0 – no bypass; 1 – 3.8 %; 2 – 6.0 %; 3 – 8.1 %, 4 – 9.6 %

4. CONCLUSIONS

Analysing the above results we can draw the following conclusions:

➢ During the operation of marine diesel engines, it is necessary to ensure their environmental performance, particularly concerning nitrogen oxides (NOx) emissions that are part of the exhaust gases. One method explored for reducing NOx emissions is the Exhaust Gas Waste-Gate (EGW), where a portion of diesel exhaust gases is directed into the exhaust gas bypassing system.

- While the use of the EGW system reduces NO_x concentration in exhaust gases, it also leads to a decrease in diesel engine power and an increase in specific fuel consumption due to the deterioration of the combustion process. Additionally, exhaust gas bypass contributes to an increase in the temperature stress on the diesel engine.
- The use of exhaust gas bypass contributes to improving the environmental performance of marine medium-speed diesel engines, particularly in the operational load range of 55–85 %, where NOx emissions in exhaust gases decrease by 3.5–15.4 %. The greatest reduction in NOx emissions occurs at loads of 75–85 %, which are common operating conditions for marine medium-speed diesel engines.
- The use of the EGW system results in an increase of the thermal stress on the diesel engine, which can be assessed by the temperature of the exhaust gases.
- To determine the effectiveness of the EGW system as a means of meeting the requirements of MARPOL Annex VI for limiting NOx emissions, a comprehensive assessment of the diesel engine's operation parameters is necessary. This includes the reduction of nitrogen oxides in exhaust gases, the increase in specific fuel consumption, and the increase in exhaust gas temperatures. The optimal level of gas bypass should be chosen based on achieving the maximum reduction in nitrogen oxide emissions with minimal increase in fuel consumption while simultaneously maintaining exhaust gas temperatures within acceptable thermal stress levels.
- The use of the EGW system is deemed effective for loads exceeding 75 %, with potential reductions in nitrogen oxide emissions ranging from 9.2 % to 15.4 %. For loads of 55–65 %, a reduction in nitrogen oxide emissions (3.3–5.6 %) is also observed, but with a simultaneous increase in fuel consumption (4.2–4.4 %). However, for certain bypass values, the diesel engine's thermal stress exceeds acceptable limits.
- These results confirm the feasibility of using the EGW system to reduce NOx emissions. However, its most rational use may be as an additional method in combination with an exhaust gas recirculation system, requiring further research.

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