

ELECTRICAL AND AUTOMATION CONTROL SYSTEM FOR A NAVAL DIESEL ENGINES LABORATORY

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This paper presents the design of the electrical and automation system for a propulsion system incorporating a diesel engine, developed for the establishment of a didactic laboratory aimed at the theoretical and practical study of marine diesel engines. A modern, customized automation system was developed for the monitoring and control of the propulsion system. Real-time engine parameters and control commands are displayed on the operator panel. Testing and evaluation activities were carried out to assess the operational behaviour of the Marine Diesel Engine Laboratory's propulsion system and to implement the automatic control program required for its reliable functioning.

Keywords: automation control system, test bench, marine propulsion

1. Introduction

Nowadays, an electrical and fully automated control system is crucial for a reliable operation of naval propulsion on board of ships [[1], [2]]. Testing these systems, as well as teaching marine students how to operate them is important before implementation on the ship.

The propulsion system facilitates the analysis of marine diesel engine operations, including the variation of propeller shaft rotation direction, torque, and brake input speed [[3], [4]].

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This paper describes the automation and electrical control system developed by our team for the Naval Diesel Engines Laboratory (LMDN), where hands-on activities with students are conducted. The drive unit is a diesel piston engine, equipped with a fuel injection system and powered by a pneumatic starter. The propulsion system integrates the custom-made supervisory control and data acquisition (SCADA) system developed by our team, as well as several components, such as a fuel tank, lubrication system, oil cooling fan, motor operated valves, as well as the instrumentation [[5]-[7]].

A propulsion system using a Volvo Penta D16 MH engine was developed for the marine engine laboratory. This 6-cylinder, in-line marine diesel engine, part of Volvo Penta's D16 series, combines high power with reliability, making it suitable for both commercial and recreational marine applications. The D16 series is known for its fuel efficiency and consistent performance, crucial for vessels requiring sustained power over long distances, such as transport ships, fishing boats, patrol vessels, and yachts [[8], [9]].

The paper focuses on presenting the automation of a test bench [[10]-[13]] for propulsion systems, that offers an optimal framework for conducting experimental tests to assess engine performance under various operating conditions. The laboratory test bench is fully equipped with essential components, including a fuel tank, lubrication system, oil cooler, filters, control and shut-off valves, as well as measurement and protection devices. A hydraulic brake simulates the propeller load on board of ships.

2. The laboratory test bench

The fully automated laboratory test bench is presented in Fig. 1 and includes: the diesel engine; reduction gearbox; multiplier gearbox, hydraulic brake simulating the propeller load; fuel supply installation driven with an electric motor operated pump, via a frequency inverter; engine cooling system driven by a motor operated fan, with variable speed via a frequency inverter, automation cabinet, drives cabinet, control console with operator panel, repeater display panel.

The signals from the sensors measuring temperature, pressure, vibration, fuel and water level, etc., enter the automation cabinet into terminal blocks, and are then wired to corresponding adapters and signal conditioners that convert the analogue signal to 4-20 mA unified current signal, which is handled by PLC inputs.

The propulsion system assembly is equipped with a command and monitoring system for the automatic control of operational processes and continuous supervision of functional parameters. The control system ensures the start-up of the propulsion installation, monitoring of operating parameters, and adaptation of operation to variations in input and output parameters within the prescribed limits, as well as protection and shutdown to prevent damage.

The design of the control and monitoring system for testing the Volvo Penta engine in the laboratory was carried out in accordance with the configuration of the command-and-control system for the Volvo Penta D16MH IMO II engine and the control and brake's monitoring scheme.

The components of the automation system are the remote console with operator panel, connection cables, Engine Monitoring System, Brake Monitoring System, JB1 – Analog Signal Junction Box, JB2 – Digital Signal Junction Box, engine start batteries and engine start contact.

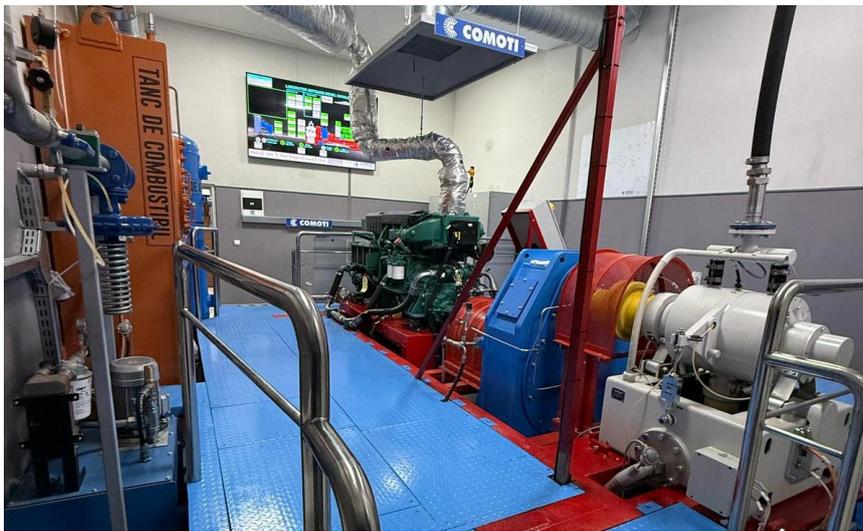


Fig. 1. Marine diesel engine laboratory

3. Supervisory control and data acquisition system

The control system (Fig. 2) comprises a drives cabinet (left) and an automation cabinet (right) integrating a VersaMax programmable logic controller (PLC) [16], produced by Emerson Automation Solutions, running a custom software application developed by our team, designed to execute the implemented logic. Parameter display and operation are carried out via the operator panel, also produced by Emerson Automation Solutions and programmed with a custom solution developed by our team [17].

The interface between the programmable logic controller and the process is achieved through the electrical equipment installed on the propulsion system. The electrical signals from the process are analogue or digital inputs to the programmable logic controller. The electric cabinet also contains the corresponding power supply circuits both for the various measurement lines and for the control of the actuating elements. The parameter list and electrical diagrams are part of the execution documentation of the automation system, outlining the wirings designed.



Fig. 2. Control cabinets

The interface with the operator for the automation cabinet (Fig. 3b) consists of signalling elements on the front of the electrical cabinet:

- green light for power presence;
- signal light tower on top of the cabinet: GREEN – normal operation; ORANGE – warning; RED – stop;
- buzzer: audible warning.

The drives cabinet illustrated in Fig. 3a includes three converters for the cooling fan motor (water-brake), the main water-brake pump, and the secondary water-brake pump, along with other electrical circuit protection equipment.

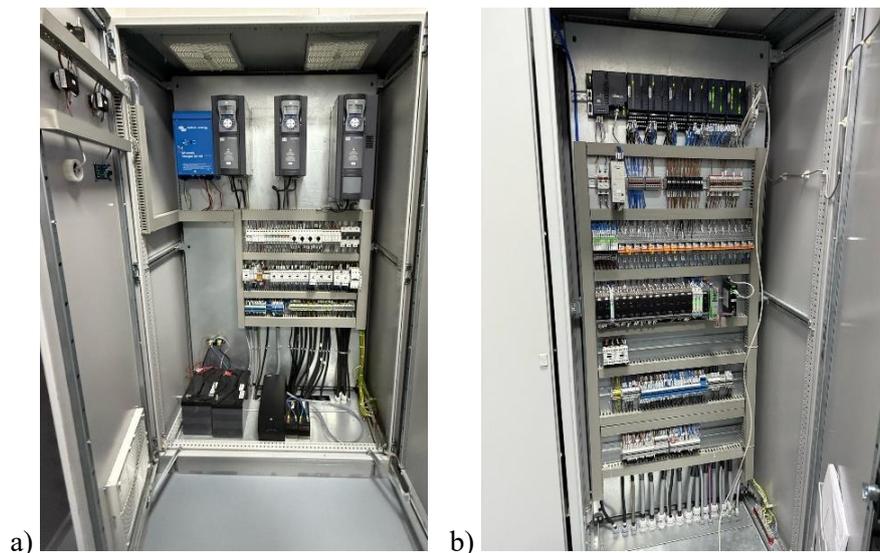


Fig. 3. a) Drives cabinet; b) Automation cabinet

The control console presented below (Fig. 4) includes the operator panel displaying the user interface, the diesel engine control lever, the engine operator panel, the brake operator panel, and other control and signalling devices.



Fig. 4. Control console (CC)

Wiring and junction boxes are installed across the propulsion system assembly (Fig. 5). The junction boxes serve the following roles:

- JB1 connects analogue signals;
- JB2 connects digital signals;
- JBM connects signals between the engine and the monitoring panel.



Fig. 5. Junction boxes

For the testing of the propulsion system, the assembly is equipped with a control and monitoring system for automatic operation and continuous supervision of functional parameters. The automation system is implemented in the final functional configuration of the propulsion system, ensuring its operation and integration with simulated ship systems and automation. The parameters measured

during the testing process, characterizing the propulsion system's operation, are automatically recorded by the LMDN automation system for further evaluation and performance analysis.

This program has been specifically developed for the testing of the LMDN propulsion system and is applicable only to this type of propulsion system. Each piece of equipment in the LMDN test bench plays a significant role in ensuring accuracy, reliability, and comprehensive testing. From dynamometers and data acquisition systems to control mechanisms and safety systems, each component uniquely contributes to the precision and efficiency of engine testing.

Fig. 6 shows a part of the ladder diagram software implemented in the PLC, programmed in Proficy Machine Edition, representing the normal operation sequence of the test bench. The structure reflects the logical flow, respecting the operations order and dependencies within the control process. The custom programmed software supports the data acquisition, data postprocessing, analysis and observing the system's operation parameters.

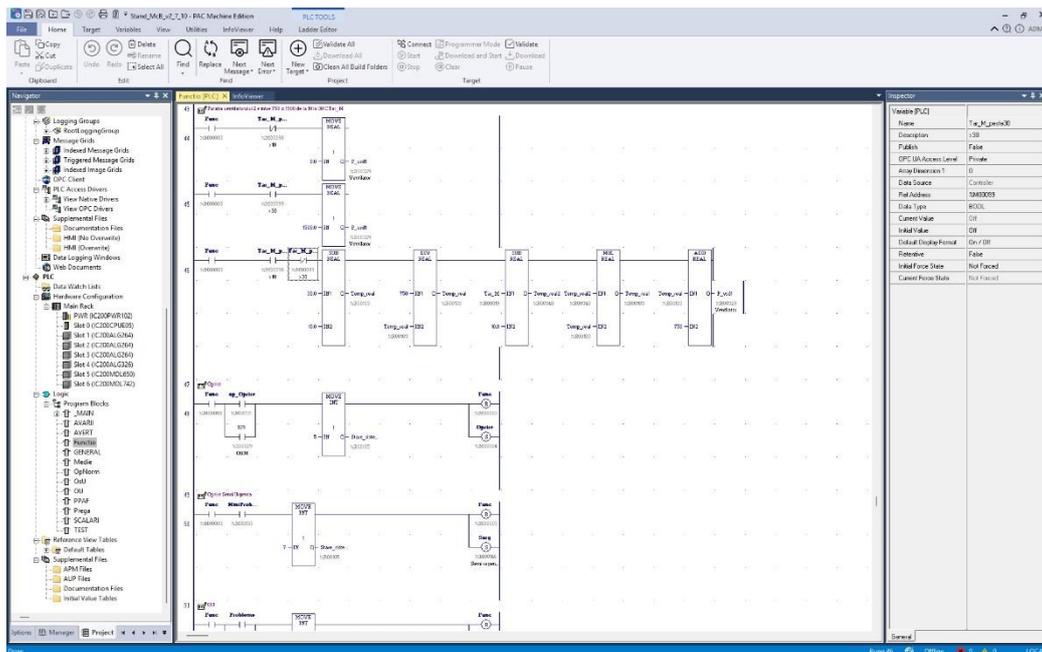


Fig. 6 Ladder diagram implemented in the PLC software

Based on the analysis of requirements and experience gained through the design and construction of multiple types of test benches by INCDT COMOTI, the input and output analogue and digital parameters were determined to ensure optimal system operation. Based on these, the monitoring and control equipment for the diesel engine was selected to meet all imposed requirements.

The automation system solution for LMDN stands out due to:

- optimized layout transducers, junction boxes, and local control cabinet;

- modern local control via touchscreen operator panel;
- three-position signal lamp for quick and remote visualization of the engine's operational mode: Green – Normal operation, Yellow – Warning, Red – Shutdown;
- optimized oil heating program for quick engine readiness;
- remote monitoring of engine parameters with essential data logging.

Propulsion system testing is performed via the automation system, whose main functions are starting, ensuring safe operation, and stopping the propulsion system, commanding and controlling the propulsion system in Simulation mode, real-time parameter visualization via the operator panel, fault and protection alerts, modifying parameter thresholds, displaying and logging shutdown causes, parameter monitoring, etc. From the automation system's perspective, the propulsion system operates in sequential mode, with the following defined states:

- **INIT** – Initial state (idle, system can be started);
- **TESTS** – Manual tests (system components can be tested);
- **OPERATION** – Operation (startup, idle run, loaded operation);
- **NORMAL STOP** – Normal shutdown sequence;
- **EMERGENCY STOP** – Emergency shutdown sequence.

When the Operator Panel (PO) is powered and the software runs correctly, several screens can be accessed via the buttons on the bottom of the MAIN screen – shown in Fig. 7 as an intuitive diagram, presenting monitored parameters and the technological scheme of the propulsion system.

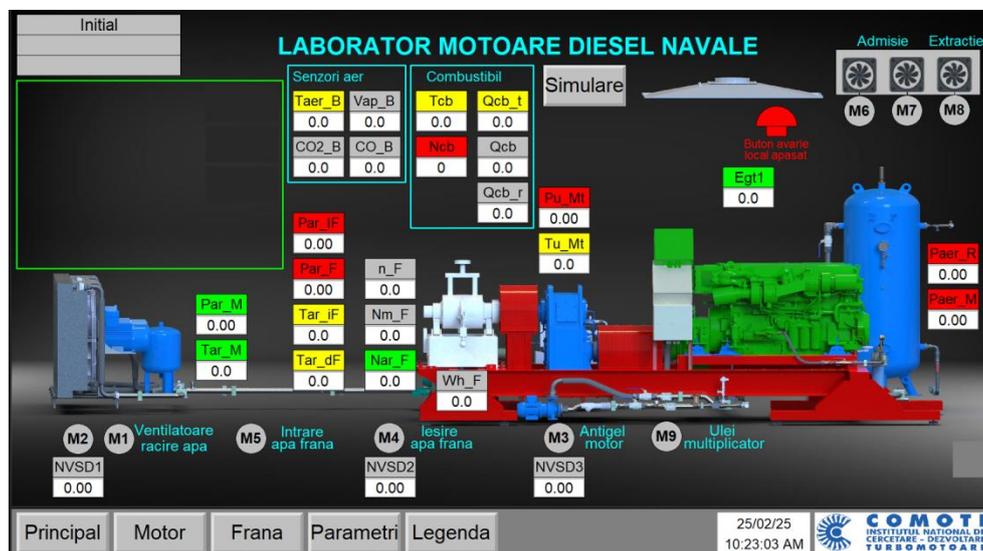


Fig. 7. MAIN screen

All propulsion system parameters can also be viewed on a single screen – PARAMETERS, representing %d_F [%] – Brake positioning valve, CO_B [ppm]

– Carbon monoxide detector, **CO2_B** [ppm] – Carbon dioxide detector, **Egt1** [°C] – Exhaust gas temperature, **n_F** [rpm] – Brake speed, **Ncb** [mm] – Fuel level, **Nm_F** [Nm] – Brake resistive torque, **NVSD1** [rpm] – Antifreeze pump speed, **NVSD2** [rpm] – Water flow off pump speed, **NVSD3** [rpm] – Cooling fan speed, **Paer_M** [bar] – Start-up pressure, **Paer_R** [bar] – Air pressure in the reservoir, **Par_F** [bar] – Brake water pressure, after regulator, **Par_iF** [bar] – Brake water pressure, before regulator, **Par_M** [bar] – Cooling water pressure, **Pu_M** [bar] – Engine oil pressure, **Pu_Mt** [bar] – Multiplier gearbox oil pressure, **Qcb** [L/h] – Inlet fuel flow, **Qcb_t** [L/h] Fuel flow, **Taer_B** [°C] – Ambient air temperature, **Tar_iF** [°C] – Brake inlet water temperature, **Tar_M** [°C] – Cooling water temperature, **Tcb** [°C] – Fuel temperature, **Tu_Mt** [°C] – Multiplier gearbox oil temperature, **Vap_B** [%LEL] – Fuel vapours detector, **W_F** [kW] – Brake power and **Wh_F** [hP] – Brake power (horse power). In testing activities, we can categorize as useful the following screens, which provide real-time, highly intuitive information:

- LEGEND (parameters and measurement units);
- FAULTS (conditions leading to system shutdown);
- TESTS (actuators of the propulsion system can be tested).

In the TESTS screen (Fig. 8), the elements of the propulsion system are presented, with the possibility to test their operation.

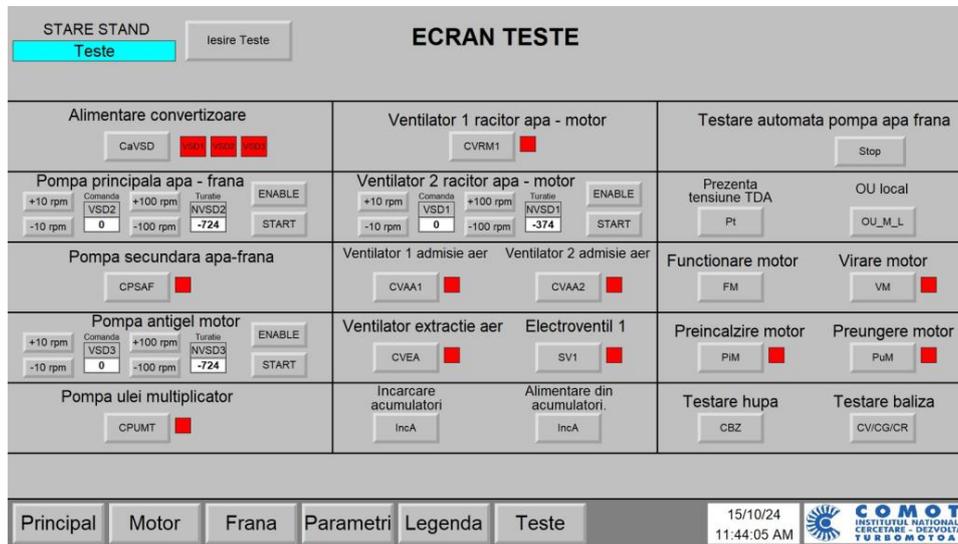


Fig. 8. TESTS screen

This is useful for commissioning and testing electrical equipment within the plant or during maintenance work. From this screen it is possible to test the operation of the water-coolant pump, converter power supply, engine antifreeze pump, multiplier oil pump, cooler fan motors/air intake/exhaust fan motors (it is possible to check the speed of the motors from 0 to nominal for direct start motors

and from 10 to 10 rpm or from 100 to 100 rpm for converter driven motors), battery charging and battery power supply and the hupee.

Propulsion system operation – startup, testing, operation, and shutdown – is automatically managed by the Control and Command System installed in the Automation Cabinet, through the software implemented in the PLC.

Startup and shutdown are executed automatically via commands from the operator panel in the engine control station (PCM). Once the engine is started and warmed up, operation mode commands and adjustments can be made from the operator panel and the throttle lever located in the PCM control console. The propulsion system's operating mode is selected by prescribing parameters for the hydraulic brake/dynamometer that simulates the propeller's characteristic curve, resulting in engine torque and developed power as a function of speed.

LMDN control is carried out by the monitoring and control system, which includes an engine control station and a propulsion system monitoring panel. These integrate a console, an operator panel, a 9" display screen, a signal processing cabinet (which includes the PLC with control software), and a drives cabinet (containing the touch panel for box 1 and backup batteries).

Sensor information is converted into standardized 4-20 mA signals using adapters that amplify, filter noise and disturbances, isolate, and linearize the signals, which are then input into the PLC.

The human operators control the propulsion system of LMDN from the operator panel in the engine control station. During commissioning, it is verified that the propulsion system operates correctly between idle and maximum load, that no functional issues occur which might endanger the LMDN mechanical assembly, that all auxiliary systems operate correctly within the diesel engine's working range, and that functional tests can begin. Parameters of the engine, brake, and other propulsion system components are recorded for the purpose of analysing behaviour during testing.

From the evolution of the brake speed (Fig. 9), it can be seen that in the chosen time interval two starts were made with the engine-gearbox-brake assembly, for each start the speed varied between zero and 1800 rpm. The exhaust gas temperature and the fuel flow can be visualized in Fig. 10. The maximum exhaust gas temperature, measured on the exhaust gas outlet section connected between the engine and the outside of the test stand, reaches a maximum value of 419.4°C, which corresponds to normal engine operation at the tested speed. The fuel flow is controlled by the engine electronic control unit and varies with the operating speed, with a peak at engine start-up, as the valve opens.

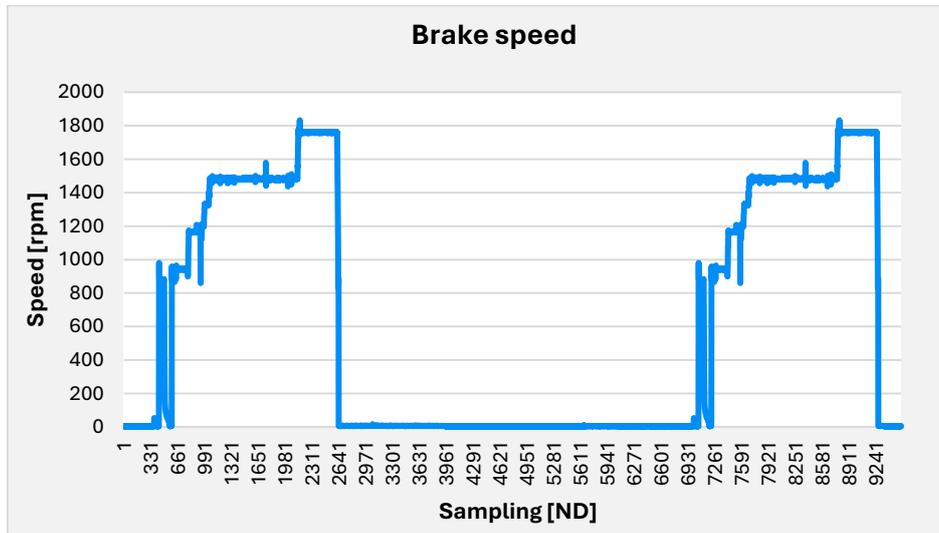


Fig. 9. Brake speed evolution

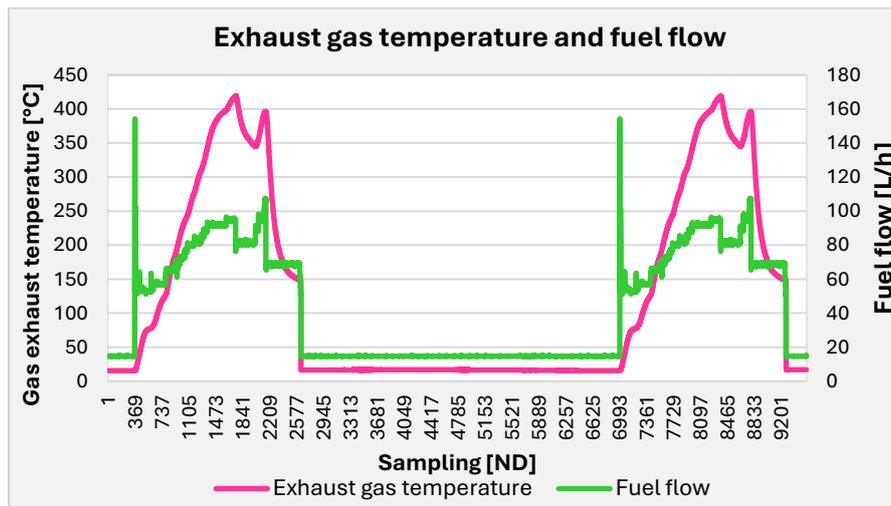


Fig. 10. Exhaust gas temperature evolution

4. Conclusions

The objective of this work was the research, design, and testing of an electrical and automation system for the monitoring and control marine diesel engine laboratory within a limited space. Following testing and tuning activities needed to ensure normal startup and operation conditions for the control system, the startup program for the entire assembly was completed.

This program will further assist in testing the overall performance of the propulsion system and in ensuring electric propulsion control and system safety by checking installations using monitored parameters.

The studied field holds major significance in the development of modern, efficient marine propulsion systems, which contribute to the theoretical and practical study of marine diesel engines. Training the cadets with practical laboratory work simulating the onboard operation of the naval engines is of great importance in preparing the future marine personnel for real missions onboard.

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