The Application of the Diesel Engine Simulator for the Diagnostic Training

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The diesel engine simulator, equipped with the specialized diagnostic model of the high power, medium speed, four stroke diesel engine is the subject of this paper. The program simulates an engine operation under various conditions and introduces various defects. The package is particularly suited to the diagnostic training, providing the instructors with a powerful teaching tool and the students with an increased understanding of the relation between the engine technical state and its operating parameters.

KEYWORDS: simulation, diagnostics, diesel engines, training.

INTRODUCTION

The idea for the role that could be played by a diesel engine simulator came to the author during the course of his work lecturing in the subject of marine diesel engine operation, maintenance and diagnostics. Originally, the requirement was for a teaching aid, to support the lectures. In a lecture hall, it is very difficult to convincingly illustrate certain aspects of a diesel engine operation; it is not possible to have a real engine on which to demonstrate, and even if a real engine is used separately to the lecture, it takes a great deal of time to set up and then monitor the faults. After using program created by the author to act as a teaching aid as described above, the response from his students made the author decide to extend the software so that it could also be used as a personal teaching aid by students in their own time. It became clear as students used the software more and more that there was a great deal of training potential in this kind of a simulator.

PROGRAM DESIGN

The first version of the PC-based diesel engine simulator, called **Turbo Diesel for Windows** was developed in 1994 [2], the latest one called **Turbo Diesel 3** (Fig. 3) was completed by the author in 2003. The 'heart' of the program is a diesel engine mathematical model, based on the physical structure of the modelled object (Fig.1). The model has been developed using the actual factory test bed results and the classic thermodynamic equations. The package allows an engine operation under selected initial conditions (for example, torque, RPM, ambient air pressure) and variable technical state (for example a dirty air blower, broken piston rings, a worn fuel pump and so on). The simulated engine reacts naturally under almost any combination of factors, although some combinations make operation impossible as they would in real life.
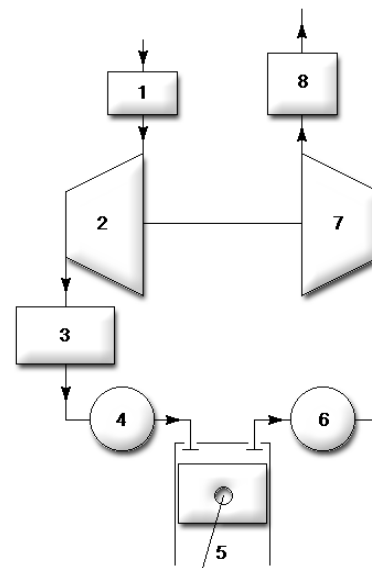

Fig. 1 The simplified model of the turbocharging system (1-air filter, 2 – air compressor, 3 – air cooler, 4- air receiver, 5 – cylinder, 6 – exhaust receiver, 7 – gas turbine, 8 – exhaust duct).

In order to validate the software, it was necessary to model an actual engine so that the calculated values produced by the software could be compared to values measured on the real engine (see Fig.2).
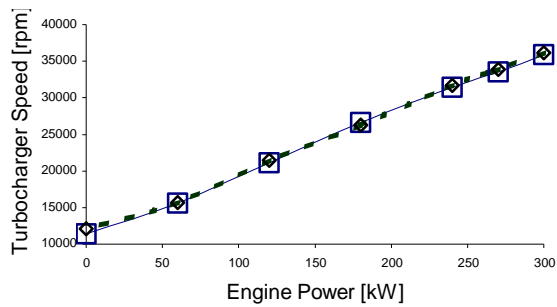
Fig. 2 The comparison of the simulated and measured (dot line and squares) turbocharger speed.

The diagnostic simulator is designed to teach the principles of the generic diesel engine operation. It is not designed to teach an operation of any specific engine or type of engine.

The simulator has been designed with a great care about the user interface. The implementation of the typical Microsoft Windows controls (i.e. menus, dialogues, pushbuttons and scrollbars) should make the simulator operation easier, especially for the user with at least basic experience with the graphics user interface. The simulator makes use of the multimedia features which are typical for today's personal computers. The digitised engine sound has been synchronised with an engine speed in order to create the typical engine room atmosphere.

The general approach to the diesel simulator application in the diagnostic teaching was based on the author's long time academic experience in giving courses on diesel engines diagnostics and on some available publications [5,6] as well. The main teaching tasks implemented in the simulator have been listed below:
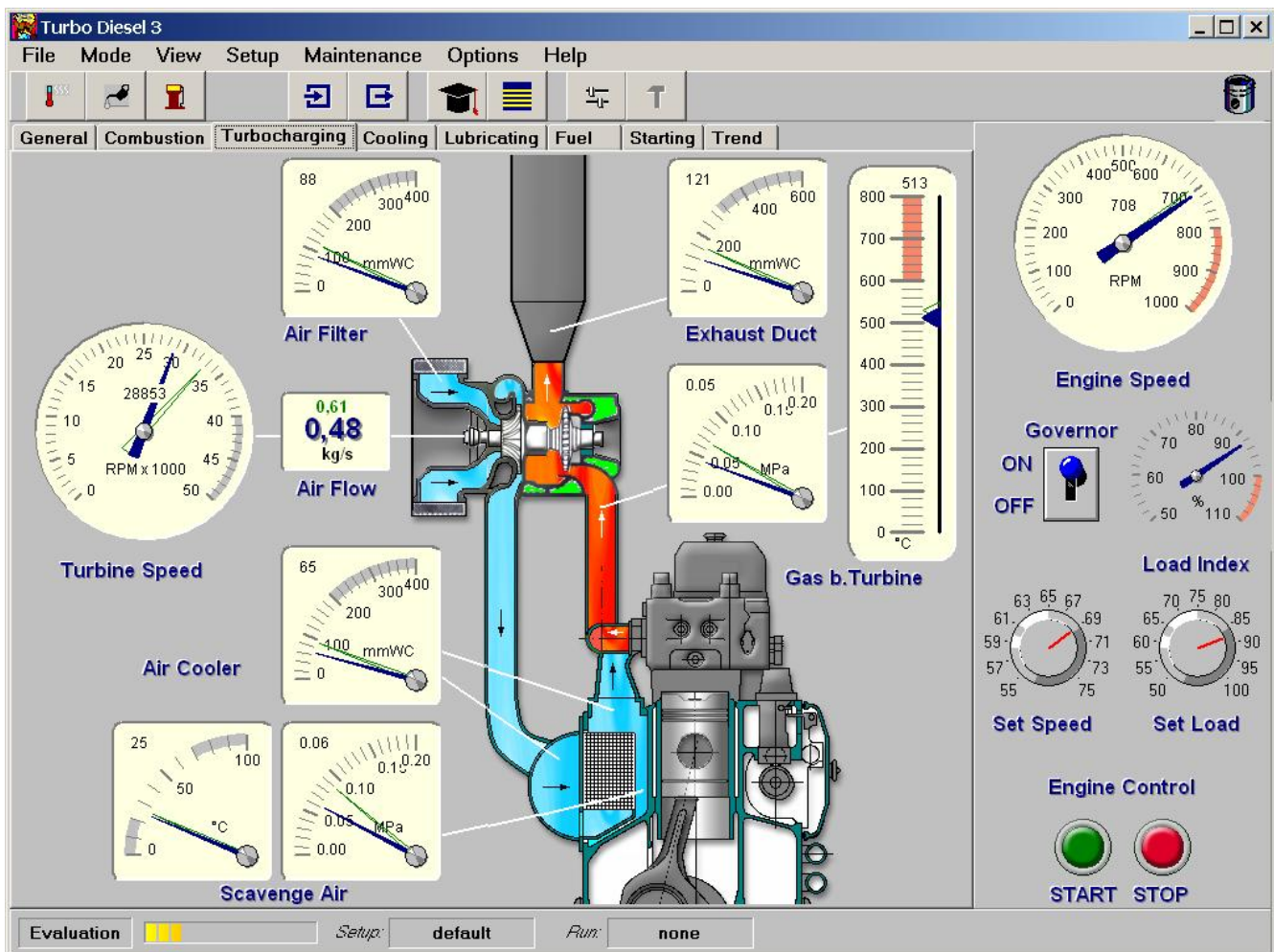

Fig. 3 Simulator main window.

- **Diagnostic principles**.
  The first requirement was for the software to teach about the relation between the diesel engine technical state and its operating parameters. This is performed by the program in 'Evaluation Mode'. In this mode a student can freely change engine load and operating conditions, can select different engine faults, mix them and see the effects of these changes by inspecting the engine parameters. The student learns to understand the relationship between an engine state and the engine parameters. This is important particularly for students early on in their training. It also makes clear the importance of the proper diagnostic method application, since only the correct diagnostic methodology can enable the identification of the engine faults.
- **Maintenance strategy and assessment**
  The second requirement was for a more pressurised mode where the student would be obliged to put his knowledge into practice - i.e. run the simulated engine and take responsibility for its condition and maintenance. In the program 'Live Run' mode, the student becomes in effect a qualified user. he needs to monitor closely the engine operating parameters and carry out repairs when necessary. Apart from reacting to the student's actions, the software also generates random wear and tear factors, which means that no Live Run is ever exactly the same as another. The student's performance is logged and scored for assessment and de-briefing.

- **Design and implementation of course material**
  The third requirement was for a lesson-mode, both for instructors to be able to create their own specific course material, and for students who could be given set material to work through. The program has a separate lesson-writing program, where instructors can create course material. These courses can then be loaded into the main program for students to complete as required.

WORKING IN EVALUATION MODE

In Evaluation Mode the student can work in the instructor's absence while trying to learn the relationship between the technical state of the engine or the operating conditions on the one hand and the operation parameters on the other.

The following list gives the recommended training plan for students:

1. The student has to start the engine and observe the operation parameters.
2. Later, he can increase and decrease the engine load and observe the parameters.
3. The trainee should find his way around the engine by changing some of the parameters and observing the effect on the gauges. The program tutorial shows how to do this and how to start making diagnoses by observing the gauges.
4. The current simulation setup and the engine parameters can be saved in the setup file.
5. The trainee can also load the previously saved simulation setup from a file, which is much faster than making a new calculation).

The current simulation setup and the engine parameters can be printed directly from the program menu.

WORKING IN LIVE RUN MODE

The Live Run mode is rather like other computer simulations (a flight simulator for example); the operator has to act as a qualified user, working against the computer, which simulates dangerous situations, faults and so on. Although the scenario is written by an author, random factors are also introduced by the computer.

Each Live Run starts with the engine in a particular technical state (set by the instructor or loaded from a previously created and saved setup). As time proceeds, any faults which are present at the outset become aggravated and affect the parameters. The student monitors the engine state and can carry out repairs or maintenance at any time; correct actions lead to more efficient and economical running while negligence, wrong or unnecessary actions lead to a loss of economical efficiency.

Time is measured in steps (the user can speed these up or slow them down at will). At the end of each time step, which he can think of as day's operation, the computer recalculates the state of the engine and gives the student his current score in dollars; the higher the score, the more efficient the student is.

The following points are worth noting:
- the student is free to inspect all the available engine parameters, perform maintenance and repairs and change the load, but cannot change the engine setup directly.
- in certain circumstances, constant engine deterioration can cause an emergency stop. This means an additional penalty on top of the repairs needed to restart the engine.

- the accumulating score is permanently shown in the special "Live Run Info" dialogue box; it will be saved together with the engine setup while saving a Live Run.
- the Live Run can be ended at any time. The current result and the cost factors will be saved automatically in the Results file, which lists all of the last fifty Live Run scores, and the student can save the current status in a special file.

Generally speaking: *the student should repair only what is necessary, when it is necessary.*

INSPECTING ENGINE PARAMETERS

There are many different diesel engine and ambient parameters, which can be continuously monitored while running the Turbo Diesel 3 model engine. Gauges show more than one value (Fig. 5). For single gauges the two readings are the current and reference value. On multiple gauges you see the actual value for each cylinder and the reference value which is common to all three. The bigger the difference between the actual and reference values the worse the technical state is. The principle that the deviations should be used rather instead of the actual parameter values is very important especially for the student without an experience of the simulated engine type (Fig. 4). He can very hardly estimate if the observed parameter value is correct so the parameter deviation is of a great help for the analysis.

Output Data

Name	Value	Units	Status	Dev.	-Dev.	+Dev.
Engine Speed	695	RPM	Normal	+1%		
Engine Power	289	kW	Normal	+1%		
Engine Torque	3993	Nm	Normal	0%		
Specific Fuel Consumfion	249	g/kWh	No alarm	+7%		
Engine Mean Effective Pressure	1.39	MPa	Normal	+1%		
Mean Indicated Pressure at Cyl.1	1.70	MPa	Normal	–1%		
Mean Indicated Pressure at Cyl.2	1.70	MPa	Normal	–1%		
Mean Indicated Pressure at Cyl.3	1.80	MPa	No alarm	+5%		
Lubricating Oil Pressure Before Engine	0.35	MPa	Normal	+1%		
Lubricating Oil Temperature after Engine	74	°C	Normal	+1%		
Cooling Water Temperature before Engine	60	°C	Normal	0%		
Cooling Water Pressure before Engine	0.25	MPa	Normal	+1%		
Cooling Water Temperature after Engine	75	°C	Normal	0%		
Air Pressure Drop at Air Filter	312	mmWC	HIGH alarm	+164%		]]]]]]]]]]]
Air Pressure Drop at Air Cooler	94	mmWC	Normal	0%		
Scavenge Air Temperature before Engine	27	°C	Normal	+1%		
Scavenge Air Pressure before Engine	0.06	MPa	No alarm	–32%	[[[	
Air Flow	0.52	kg/s	No alarm	–15%	[	
Exhaust Gas Temperature after Cyl.1	529	°C	HIGH alarm	+18%		]
Exhaust Gas Temperature after Cyl.2	608	°C	HIGH alarm	+36%		]]]
Exhaust Gas Temperature after Cyl.3	504	°C	HIGH alarm	+13%		]
Max. Combustion Pressure at Cyl.1	7.2	MPa	No alarm	–27%	[[	
Max. Combustion Pressure at Cyl.2	8.6	MPa	No alarm	–14%	[	
Max. Combustion Pressure at Cyl.3	11.0	MPa	No alarm	+11%		]
Exhaust Gas Temperature before Turbine	604	°C	HIGH alarm	+14%		]
Exhaust Gas Pressure before Turbine	0.05	MPa	No alarm	–29%	[[	
Exhaust Gas Pressure after Turbine	167	mmWC	Normal	0%		
Turbocharger Speed	28966	RPM	No alarm	–12%	[	

Close

Fig. 4 The parameter deviations shown in Output Data window.
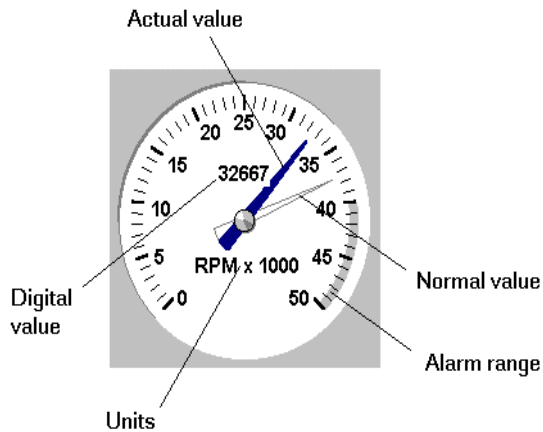
Fig. 5 Different parameter values at the single gauge**.**

The gauges are combined into panels to group related parameters logically. The example of the lubricating system panel has been shown below (see Fig. 6).

CHANGING THE ENGINE SETUP

The technical state of the engine elements, as well as the engine load and operating conditions, can be changed with the program setup. The engine fault simulations are connected with a turbocharging system, combustion chamber, fuel system, cooling system and a lubricating system. The simulations can be mixed freely although some combinations make operation impossible as they would in real life (Fig. 7).
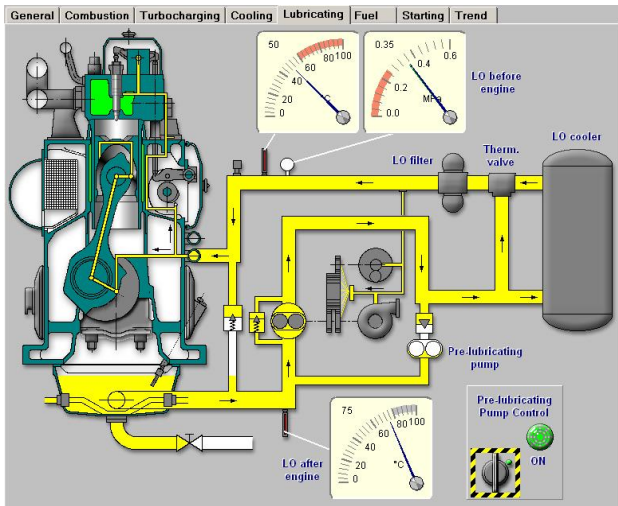

Fig. 6 Lubricating system panel

Here is the example list of the turbocharging system possible simulations:
- air filter - increase in air path resistance
- air blower - decrease in air flow efficiency
- gas turbine - increase in gas path resistance
- air cooler - decrease in air resistance

Some of the operating conditions can be also changed and they are listed below:
- engine speed
- engine load
- ambient air pressure and temperature
- cooling water pressure and temperature
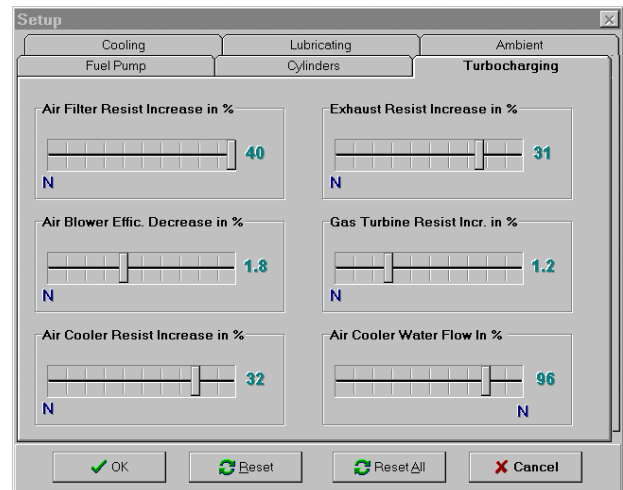- lubricating oil pressure and temperature

Fig. 7 The simulation mixing window

Every change in the technical state or in the operation conditions starts the calculation process. The calculation loop has to be repeated many types until the balance conditions listed below are fulfilled:
- the power required by the air compressor has to be balanced with the power produced by the gas turbine within the given range.
- the air mass flow delivered by the air compressor has to be balanced with the gas flow consumed by the gas turbine within the given range.
- the pressure drop on all passive flow resistors has to be balanced with compression ration produced by the air compressor.

It takes up to a few seconds until the engine parameters are stable depending on the actual fault setup.

The Setup Expert (Fig. 8) which has been also integrated in the simulator can always explain the relation between the change in the engine setup and the change in operation parameters, as this is very important when learning about engine diagnostics.
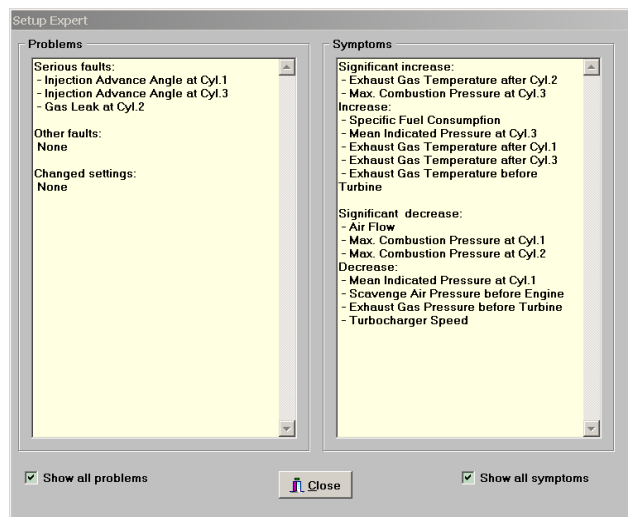

Fig. 8 Setup Expert window

The package enables a student to carry out maintenance and repair in the live run mode. He will be told when a particular activity was last carried out, as well as its price. The example maintenance and repairs are listed below:
- cooling pump repair
- water cooler cleaning
- cooling system washing.
- oil filter and cooler cleaning
- turbocharger air side washing
- turbocharger gas side washing
- air filter cleaning
- air cooler cleaning
- exhaust system cleaning
- fuel pump adjustment.

The global cost of the selected repairs is added to any previous repair and maintenance costs. This is a very important measure of his competency and can be used for his assessment. The engine user who has spent less money for the simulated engine operation costs (maintenance, repairs and fuel) will be usually more wanted by the company as the other one who produces higher operation costs. The author's experience has shown that for example the trainees with a significant practice as engineer officer at sea require less money on the simulated engine running than the young inexperienced cadets.

CONCLUSION

More than twenty years of the author's experience of different types diagnostic simulators have proved that this kind of a simulator can be successfully used for marine engineers education and assessment. The power of the personal computers combined with multimedia features, like sound and animation, makes the simulation reasonably fast and realistic. Even if this kind of a simulator cannot replace the laboratory with the actual engines, it can surely extend their capabilities.

The very important feature of a presented simulator is its low cost and the possibility to be used also for stand-alone education. This makes such a kind of a simulator very attractive for low budget colleges in developing countries, and for the ship owners, because of the possibility to be installed also on board. The well cut, complete teaching program and a set of pre-prepared lessons should be always a part of a simulator package.

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