AN INNOVATIVE SOFTWARE TOOL FACILITATES MAINTENANCE ESTIMATION OF AGRICULTURAL MACHINERY DIESEL ENGINE

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Abstract

Diesel engine maintenance of the self-propelled agricultural machinery is a very complex task requiring not only specialized technical skill and experience but also effective integration of many sources of information. In workshops, maintenance mechanics make extensive use of common knowledge, technical manuals and tester devices readings. Difficulties in maintenance arise from the need to rapid fault diagnosis and repair of the engines and the continual technical training of the mechanics in the new technology standards. Thus, there is a need to overcome these factors. This paper describes an information system (TESTA_TOOL), which is a useful tool for maintenance mechanics to generate rapid and precise fault diagnosis of the diesel engines of different kind of machinery (as the self-propelled agricultural machinery). This preventive maintenance software system can process data inserted by the user. These data are combined with operating parameters and qualitative information about a diesel engine maintenance history to alert mechanics to the slightest changes in data received (i.e. symptoms of a technical problem). It uses an intelligent system architecture, which integrates knowledge database, inference engine, user interface, and hypermedia system. The TESTA_TOOL was designed in order to satisfy the requirements of the technical sections of the companies selling agricultural machinery in Greek market and for farms with a possibility to support an information system for organizing and managing the maintenance of their machinery.

Introduction

The diagnosis and maintenance of the diesel engines mounted on heavy-duty machinery (as the self-propelled agricultural machinery) represents a very complex interdisciplinary engineering task. Diagnosis is defined as a process of locating the exact causes of a failure. Maintenance is defined as the process of correcting a component failure, usually by replacing this component with a new one, and includes three basic steps: service, inspection and repair. Service includes all steps taken to preserve the nominal state of the diesel engine and to prevent the failure. Inspection includes the required steps to test and evaluate the current situation of the investigated diesel engine in order to detect the failure at an earlier stage and to take preventive measures. Repair involves all steps taken to restore the nominal state of the diesel engine (Patel and Kamrani, 1996). The preventive maintenance becomes increasingly important, as diesel engines become more complex and costly. The technical condition controlling of the diesel engines reduce downtime and increase productivity of the machinery. Early troubleshooting allows the mechanics to make maintenance planning before the machine actually breaks down.

The technical diagnosis is based on two different estimation forms of the failures. The first form concerns the quantitative estimation of the instantaneous technical condition related to mechanical parts by generic diagnostic signals. The second form concerns the localization of the mechanical parts with failure, like: pistons, cylinder liners, valves, injectors, etc. Therefore, it was necessary to standardize all diagnostic signals, which could give adequate information on the technical conditions of the diesel engine. Maintenance is provided by a resource of diagnostic signals: $S=\{s_1, s_2, \ldots, s_n\}$, where s_i is an individual diagnostic signal in S. A resource may be either a base resource or a complex resource. A base resource is affected only by its own failure, while complex resources are affected by the failure of resources on which they depend (Wells and Langwortthy, 1999). These signals are combined with operating parameters and qualitative information about diesel engine maintenance history to alert maintenance mechanics to the slightest changes in data received (i.e. symptoms of a technical problem) (Grigoriu, 1999).

Methods for making available, by computer, judgmental subject matter knowledge are emerging much more slowly than computational methods. One reason for the unavailability of judgmental knowledge is that, typically, it must be expressed in symbolic rather than numerical or analytic form. Thus, it is necessary to develop methodologies for eliciting the knowledge and representations, which can be conveniently manipulated by a computer (Kumamoto et al., 1984). Expert systems are information systems that contain expert knowledge on a particular problem and perform inference when new data is entered. They provide a solution that is expected to be similar to the solution provided by experts in the field. An expert system usually consists of several parts: 1) a knowledge base, where the expert knowledge resides, 2) a data base, where historical and new data is stored, 3) an inference machine that provides different types of inferences, 4) an efficient interface to users, 5) an explanation module that would provide an explanation of how and why a certain decision was recommended by the system, 6) a module that learns and accumulates new knowledge, based on the system's operation and on new incoming data (Duda and Shortliffe, 1983).

While the quality and reliability of maintenance information systems are very important, most crucial aspect of these systems is their Graphical User Interface (GUI) (Hu et al., 1999). GUIs developed from a knowledge acquisition process based on experienced engineers' knowledge formation. GUIs provide the user of computer a friendly environment with a visual approach. Hence, data entry becomes much easier due to visual aid and it can post-process the results providing the user with instant feedback. GUIs utilize high-level languages to communicate with operating system software, like Windows, to provide the user with an aesthetically pleasing interface (Depcik and Assanis, 2005).

In the past several years, many researchers employed in developing different fault diagnosis systems of the diesel engines. Jardine et al. (1989) report an examination of the method of proportional hazards modelling (PHM) to determine whether or not PHM could improve on the accuracy of the oil-analyst/expert system in determining the risk of failure of a diesel engine. Gelgele and Wang (1998) describe an expert system application for automotive engines. A new prototype named EXEDS (expert engine diagnosis system) has been developed using KnowledgePro, an expert system development tool, and runs on a PC. The purpose of the prototype is to assist auto mechanics in fault diagnosis of engines by providing systematic and step-by-step analysis of failure symptoms, offering as well maintenance or service advice. The result of this development is expected to introduce a systematic and intelligent method in engine diagnosis and maintenance environments. Grimmelius et al. (1999) describe and compare three different state-of-the-art condition-monitoring techniques: principles, feature extraction, and neural networks. Two condition monitoring cases, taken from the marine engineering field, are explored: condition monitoring of a diesel engine, using the torsional vibration of the crank shaft only, and condition monitoring of a compression refrigeration system, using various sensors. Attention is also paid to the detection of sensor malfunction as well as the user interface. The experience from the cases shows that all techniques are showing promising results and can be used to provide the operator with information about the monitored machinery on a higher level. Lebold and Thurston (2001) describe the requirements for a general Condition Based Maintenance (CBM) and prognostic system. The defined CBM architecture is being applied in demonstrations across a variety of different CBM applications. Currently, an effort is underway at the Applied Research Laboratory to develop an Open System Architecture (OSA) compliant CBM system using the Diesel Enhanced Mechanical Diagnostics Test Bed (DEMDTB). Su et al. (2001) examine what and how cognitive types affect problem solving and analyzed the theoretical development of the relationship between human cognition and the use of intelligent machines in the domain of maintenance. As a case study, a fault recovery expert system for the Maintenance Department of the diesel engine bus system of Taipei City has been developed. Findings of the study have important implications in expert system interface design, in the maintenance area. Tafreshi et al. (2002) describe an informative wavelet algorithm, which was based on extremely noisy, time-variant and transient vibration signals to obtain dynamic information and provide fault classification in diesel engines. Mustapha et al. (2004) propose an intelligent knowledge-based system for assisting mechanics and engineers to generate rapid and precise fault diagnosis of the aircraft engines. Pernestal et al. (2006) describe a Bayesian approach to fault isolation with application to diesel engine diagnosis. Given a set of measurements from the system and a set of possible faults, the task is to compute the probability that the faults are presented. Oil monitoring technology is a useful method in condition monitoring and fault diagnosis for the machine, especially for low-speed, heavy-load, reciprocated and lubricated diesel engine equipment. But it is difficult to implement intelligent diagnosis because monitored information lacks logical relationship in oil monitoring. To solve this problem, Zhao et al. (2006) adopt the theory and method of case-based reasoning for data processing and fault analysis in oil monitoring with a multi-agent system structure.

This paper presents an information system (TESTA_TOOL), which is a useful tool for maintenance mechanics to generate rapid and precise fault diagnosis of the diesel engines. The objectives of this project are focused on: a) developing an applied software tool as an intelligent maintenance support system, for diesel engines of self-propelled agricultural machinery, b) developing a user-friendly interface and c) processing large quantities of statistical and specification data.

Materials and Methods

This section describes the main components of the developed TESTA_TOOL software system: the knowledge representation, the hypermedia system, and the system configuration and functions. This software system is an automated diagnostician aimed at dealing with diesel engine complexity and it is suggested for use in conjunction with tester devices, which can observe and manipulate malfunctions from diesel engine. In the experimental setup included the following tester devices: Vibrotest 60 (Bruel & Kjaer Vibro), Filtromat OF 5 with Fluid Control Unit FCU 2010 (HYDAC International), Gas Test Plus (C’evertest Italia), and Electrical Dynamometer Model XT200 (N. J. Froment). The architecture of the developed software system is illustrated in Figure 1.

The fault diagnosis software system first of all uses the resource group of symptoms and test results, which are selected by tester devices. The actual fault(s), which occur, can only be detected by deduction from different symptoms and test results. The relation between fault, failure, symptom and test result is illustrated as: [Fault > Failure > Symptom > Test Result]. This relation is very important for safe and efficient operation and maintenance, since the generated symptom from an intervention, such as a repair action, must be determined. The problem is such that a failure may be caused by more than one actual fault, while a fault can also be identified using many symptoms and test results. Rule Based Reasoning is an intelligence technique that uses explicit relations between symptoms, test results and faults to guide problem solving. Under a normal condition, the system only displays the trend of each tested variable. When an abnormal condition occurs, the inference engine provides a hypothesis of a possible problem area in which a fault has occurred or is likely to occur. In a second phase, the inference engine will automatically provide further fault analysis. The fault checking inference engine will be assisted in this task by asking the maintenance mechanics for more detailed information obtained direct by tester devices.

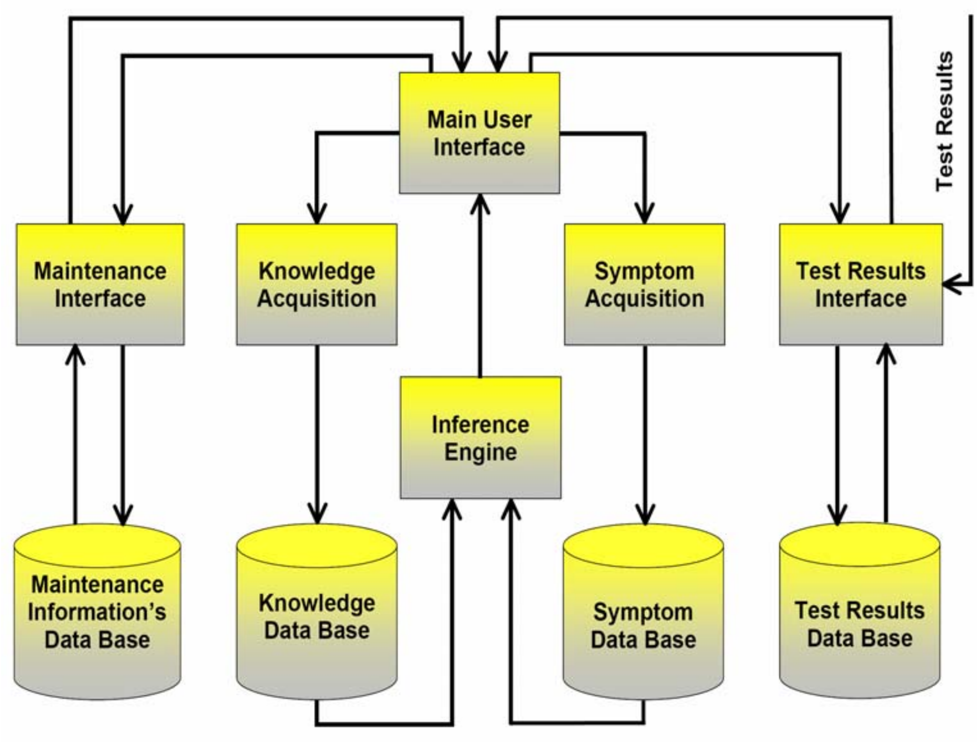


Figure 1: The architecture of TESTA_TOOL software system

The knowledge database and inference engine are the two most important components of the developed TESTA_TOOL software system. The knowledge is acquired from two different sources: 1) domain experts and 2) workshop manuals or other technical documentations.

The first of the sources is particularly notable, because this is the only way to obtain experience and private knowledge. The domain experts that selected to be the primary knowledge source for the project had a background as agricultural machinery mechanics; they were chosen for the project because they would be competent with the technical literature and comfortable with the computer-related aspects of the project. Two members of our research team were assigned as the knowledge engineers. Mechanics and knowledge engineers developed a close working relationship and did a thorough job of establishing troubleshooting task to a set of IF-THEN propositions. The knowledge acquisition process started with all of the technical information available for the diesel engines. The team then asked, "what can go wrong?" and "what would be the symptoms?". This analysis led to a complete list of major technical problem areas together with symptoms for each area. It was then a relatively straightforward task to link this information with various checks and tests in order to develop the required heuristics. Much of the knowledge came from technical manuals and historical documents. The knowledge acquisition phase has proven to be the most difficult and time consuming.

The knowledge database is just composed of the basic elements IF-THEN rules. An example of the rule database for engine condition monitoring is shown in the following Table 1. It should be noted that a modified genetic algorithm is used for knowledge self-learning of the TESTA_TOOL software system. Prior to generating the rule prototypes from the diagnosis cases and then the practical diagnosis rules are obtained by optimisation using the modified genetic algorithm. Some of the rules can be draw as a final conclusion directly from the tester devices signals and other rules, such as 09 and 10, may be joined in a combination AND’S and OR'S gates, depending on the nature of the knowledge. AND'S are indicated in the rule and OR'S are indicated by separate rules.

Associated with the information provided by the knowledge database, TESTA_TOOL can diagnose the failure corresponding to the symptom shown out by employing the inference engine. The inference engine utilizes two kinds of reasoning mechanisms and search control: forward and backward chaining reasoning. In forward chaining reasoning, the inference engine starts with the facts and reasons through the rules in the knowledge database until it has reached some conclusion regarding the condition of the diesel engine. In backward chaining reasoning, the reverse occurs: a hypothesis of a faulty component is entered into the system and the reasoning mechanism checks that conclusion against the given facts. TESTA_TOOL utilizes a conventional backward chaining reasoning to access the rules and elicit information from the user so as to arrive at a diagnosis. Backward chaining reasoning was selected because it gives results faster and has less storage requirements than the other search methods. For each failure, all likely causes have been identified and arranged in order of likelihood of occurrence.

Table 1: Examples of the rule database

RULE 09	
IF	CRANKSHAFT ANGULAR ACCELERATION IS DECREASED AND SPECIFIC FUEL CONSUMPTION IS INCREASED AND HEAD ENGINE VIBRATION LEVEL IS CHANGED
THEN	SEARCH VALVES _BREAKDOWN (70%)
RULE 10	
IF	CRANKSHAFT ANGULAR ACCELERATION IS DECREASED AND SPECIFIC FUEL CONSUMPTION IS INCREASED AND HEAD ENGINE VIBRATION LEVEL IS CHANGED AND BLOCK ENGINE VIBRATION LEVEL IS CHANGED
THEN	SEARCH VALVES _BREAKDOWN (82%)

A fault diagnosis system requires an interactive exchange of textual and graphical information between the system and the user. This calls for a hypermedia system. A hypermedia system is a specific kind of technology that attempts to organize sophisticated information databases in a more efficient and effective way. The most commercial hypermedia systems being available today provide various useful ways: text, tables, graphics, curves plotting, pictures and video information, etc. A hypermedia system has been developed, which is based on recorded maintenance activities, specification data, test results, knowledge data and object oriented programming techniques. This is a powerful hypermedia system environment permitting users to handle these types of information. Also, hypermedia system could be used in developing reference operation manuals. These manuals can provide different information and guide the user to search for topics and interactive data.

The modelling efforts have focused on the development of the following subsystems: 1) interactive diagnosis system, 2) view data system, and 3) maintenance system. Thus, the TESTA_TOOL consists of three levels of submenus, which are operated by the various users (novices in maintenance, maintenance mechanics, section reliability managers and operators of agricultural machinery). These menus provide accessibility to the followings functional modules: 1) Diagnosis: This function is for interactive troubleshooting, when different symptoms enter to the system, this function provides fault diagnosis using the symptom database, the knowledge database, and the inference engine. 2) View: This function permits test results enter from the tester devices and access into technical logbook and specification data of the investigated diesel engine. 3) Maintenance: This function contains all general information relating to the investigated diesel engine, and particularly it highlights the inspection, overhauling and adjustment procedures, as well as the main instructions for dismantling and reassembling operations.

Therefore, the TESTA_TOOL engine diagnosis is transparent to each user. It is able to communicate with users that have different levels of knowledge about computer systems. Also, the user does not have to memorize commands or certain syntax. The typical user is assumed to be a technically oriented person, but he may or may not have adequate and specialized training in each of the special kind of diesel engines and its subsystems or other components and the related repairs.

Finally, the TESTA_TOOL software system was designed to run on IBM PC-compatible computer with Pentium 166 processor or higher, 64 Mb of RAM, 340 Mb of hard disk space, 128 MB graphics adapter card, CD-ROM drive (for installation), mouse or other pointing device. Software Requirements: Microsoft Windows 98/Me/NT with SP6/2000/XP/Vista.

Results and Discussion

TESTA_TOOL software system is still a prototype system that takes advantage of windows approach. The screen layout ensures that all system functions are always accessible and eliminates the need for the user to memorize different screen configurations. When starting Microsoft Windows and clicking the icon for the TESTA_TOOL, the first page appears on the screen (Figure 2). From the next screen, which followed by the main menu, all the functions of TESTA_TOOL are accessible to the user. The main menu consists of five items: File, Diagnosis, View, Maintenance and Help (Figure 3). We shall now describe each item in brief.

FILE>EXIT. When selecting this item, it terminates the session with the TESTA_TOOL environment and returns the control to the Windows operating system. The user uses this item to exit from the TESTA_TOOL environment because other methods may result in damage to files that have not been properly closed.

DIAGNOSIS>ENGINE. The example screen is shown in Figure 4. This item starts the consultation session with the user. First, the user selects the diesel engine type for this case. After selection, the system starts the dialogue with the user. TESTA_TOOL imposes questions to the user. Possible answers of the user are the following: 1) Certainly Yes, 2) Rather Yes, 3) Perhaps Yes, 4) Perhaps No, 5) Rather No, and 6) Certainly No. After diagnosis key pressing, the TESTA_TOOL presents the "logically" conclusion. The "Quit" key permits the user to temporarily stop the consultation session to continue some other time. However, the data are stored in a case file. The user can repeat the dialogue with this case file at a later time.

VIEW menu items consist of the following: Logbook, Statistical Analysis, Engine Database and Graphs. VIEW>LOGBOOK item keeps the maintenance activities and records the defect-rectification processes of the engines to assist engineers and mechanics. VIEW>STATISTICAL ANALYSIS item provides faults statistical analysis of each engine type, and the results can be saved in a file. VIEW>ENGINE DATABASE item gives the user of the system the possibility to add, edit and obtain the specifications of each or all-together engine types (Figure 5). VIEW>GRAPHS item covers diagnostic signals (test results) that entered manually by tester devices. The user can represent the trend of each analog variable with computer graphics and can indicate of when values were out of the measurement range. In addition, the user can observe any point on the curve using the mouse. Figure 6 shows the record of the vibration FFT spectrum at n^{th} point of the engine block. When a malfunction has been verified for example "increase vibration level at n^{th} point of the engine block", the defect is entered to the engine diagnosis item so that to display the maintenance instructions.

Figure 2: Overview of the first page of the TESTA_TOOL software system

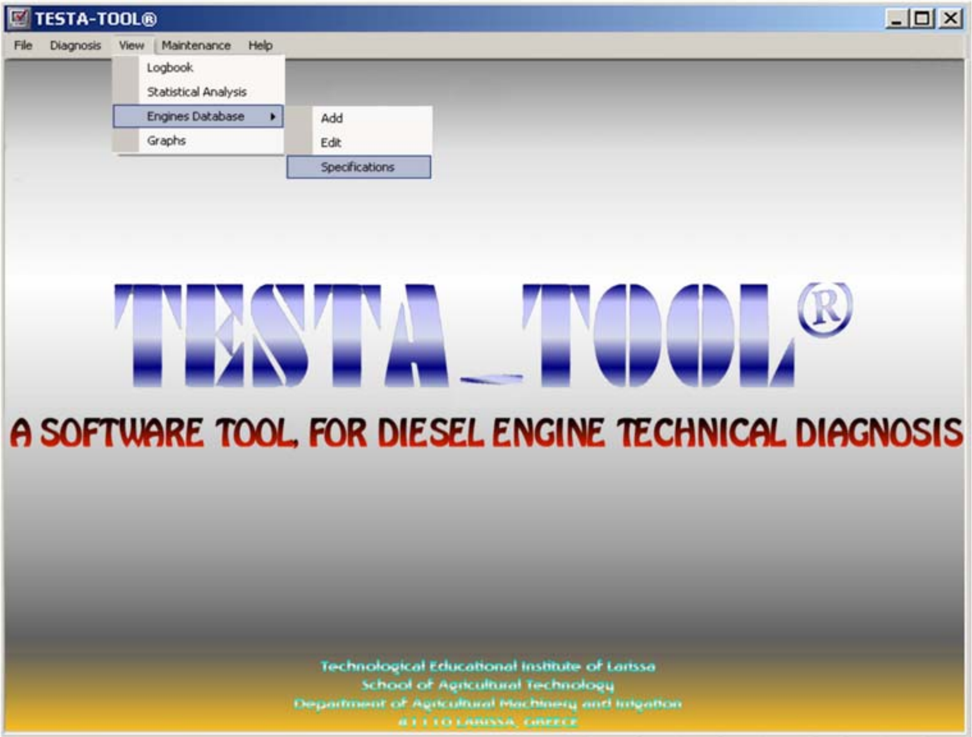


Figure 3: The main menu item of the TESTA_TOOL software system

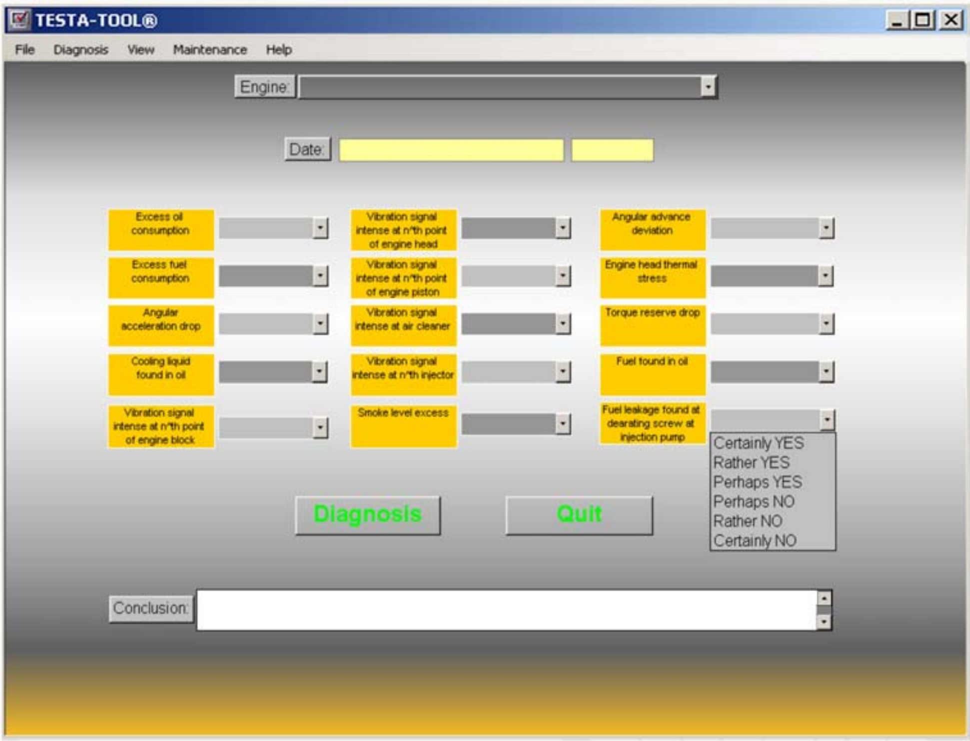
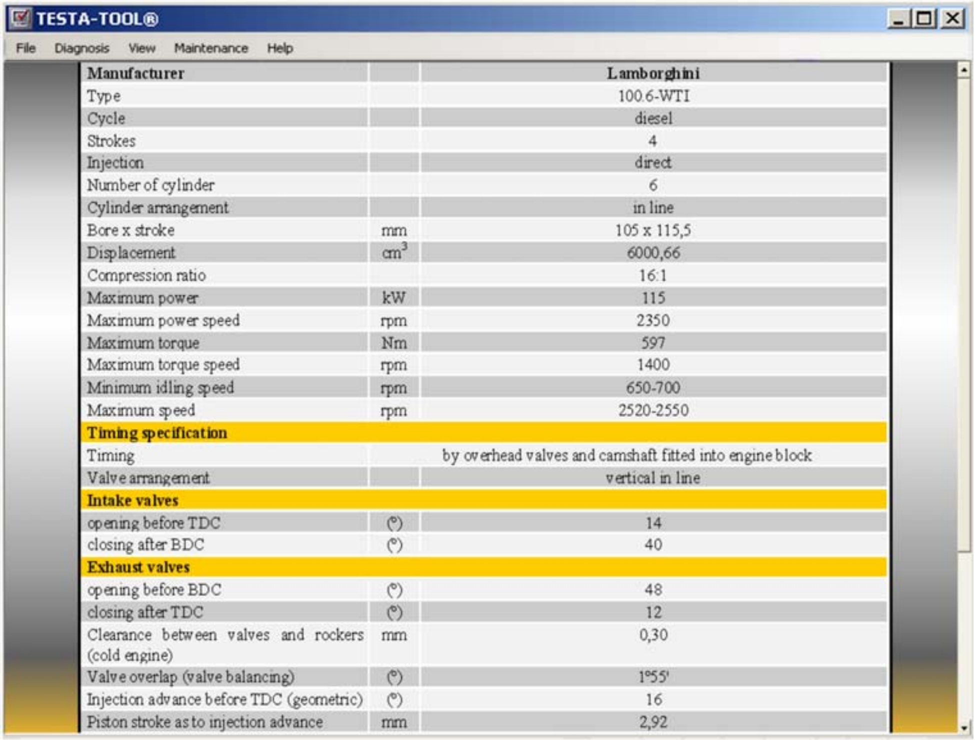


Figure 4: The screen for engine diagnosis



Manufacturer		**Lamborghini**
Type		100.6-WTI
Cycle		diesel
Strokes		4
Injection		direct
Number of cylinder		6
Cylinder arrangement		in line
Bore x stroke	mm	105 x 115,5
Displacement	cm^3	6000,66
Compression ratio		16:1
Maximum power	kW	115
Maximum power speed	rpm	2350
Maximum torque	Nm	597
Maximum torque speed	rpm	1400
Minimum idling speed	rpm	650-700
Maximum speed	rpm	2520-2550
Timing specification		
Timing		by overhead valves and camshaft fitted into engine block
Valve arrangement		vertical in line
Intake valves		
opening before TDC	(°)	14
closing after BDC	(°)	40
Exhaust valves		
opening before BDC	(°)	48
closing after TDC	(°)	12
Clearance between valves and rockers (cold engine)	mm	0,30
Valve overlap (valve balancing)	(°)	1°55'
Injection advance before TDC (geometric)	(°)	16
Piston stroke as to injection advance	mm	2,92

Figure 5: Example screen with specifications of the engine Lamborghini 1000.6-WTI

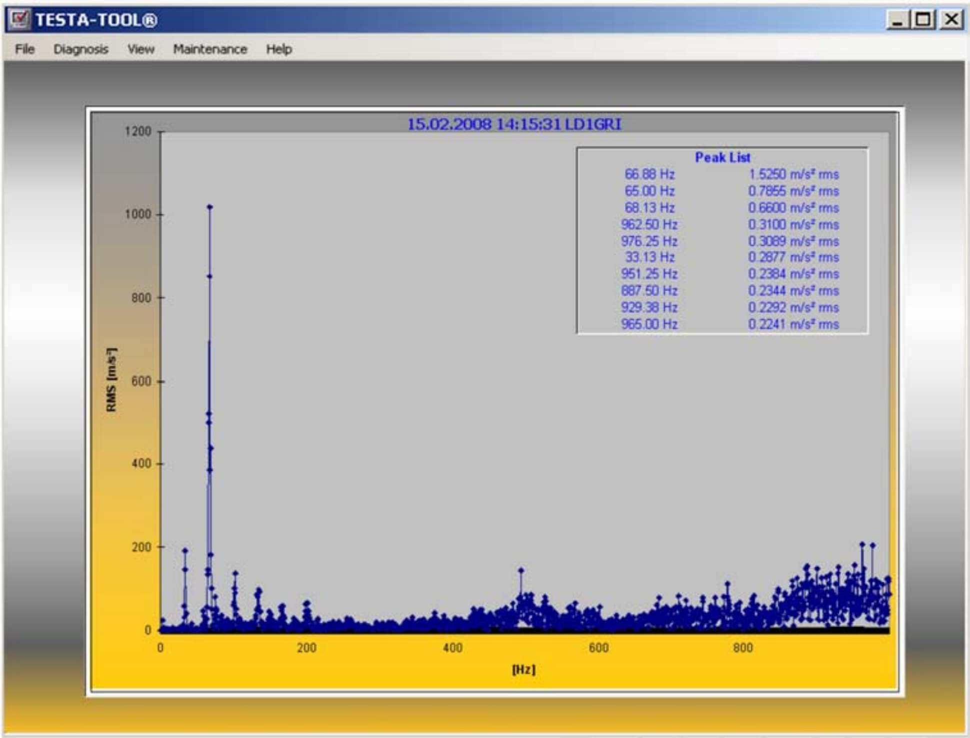


Figure 6: Example screen with recorded graph of the vibration FFT spectrum at n^{th} point of the engine block (Lamborghini 1000.6-WTI)

MAINTENANCE>WORKSHOP MANUALS & >TROUBLESHOOTING CHARTS. These items activate the session that is well suited to teach systematic and illustrative fault diagnosis techniques. They provide maintenance instructions about the fault and its recovery techniques. Specially, they give visual explanations of important engine systems and procedures for adjusting engine parameters by form of workshop manuals (Figures 7) and troubleshooting charts.

HELP>HELP. When selecting this item, the help facility is activated. The user can find information's about the existing items. The help text is descriptive and efficiently organised. It facilitates the user to understand each function of the TESTA_TOOL software system.

In order to demonstrate TESTA_TOOL diagnostic capability, we shall now present a case study from its application. Firstly, the system provides a series of symptoms to the user. Based on these symptoms, the user reply:

EXCESS OIL CONSUMPTION

1.Certainly YES 2.Rather YES 3.Perhaps YES 4.Perhaps NO 5.Rather NO 6.Certainly NO

#Certainly NO#

ANGULAR ACCELERATION DROP

1.Certainly YES 2.Rather YES 3.Perhaps YES 4.Perhaps NO 5.Rather NO 6.Certainly NO

Rather YES

EXCESS FUEL CONSUMPTION

1.Certainly YES 2.Rather YES 3.Perhaps YES 4.Perhaps NO 5.Rather NO 6.Certainly NO

#Certainly NO#

FUEL FOUND IN OIL

1.Certainly YES 2.Rather YES 3.Perhaps YES 4.Perhaps NO 5.Rather NO 6.Certainly NO

#Certainly NO#

TORQUE RESERVE DROP

1.Certainly YES 2.Rather YES 3.Perhaps YES 4.Perhaps NO 5.Rather NO 6.Certainly NO

#Certainly NO#

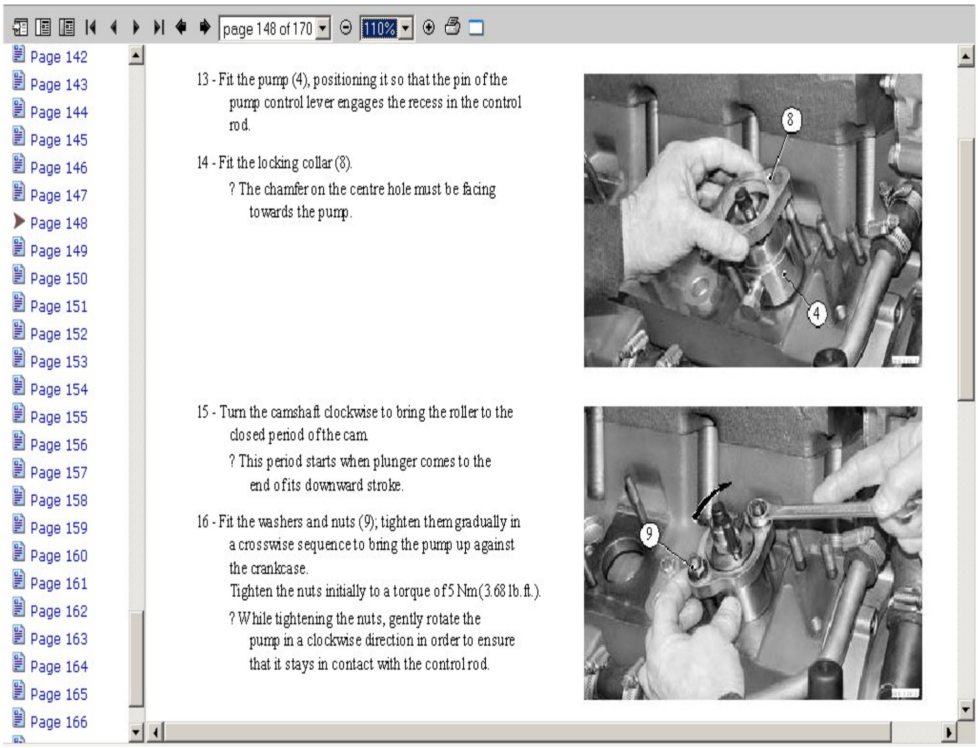


Figure 7: Example screen for reference workshop manual: Engine Euro 2 Series 1000/3-4-6 cylinders (SAME DEUTZ-FAHR ITALIA S.p.A.)

FUEL LEAKAGE FOUND AT DEARATING SCREW AT INJECTION PUMP

1.Certainly YES 2.Rather YES 3.Perhaps YES 4.Perhaps NO 5.Rather NO 6.Certainly NO

#Certainly YES#

SMOKE LEVEL EXCESS

1.Certainly YES 2.Rather YES 3.Perhaps YES 4.Perhaps NO 5.Rather NO 6.Certainly NO

Certainly YES

ANGULAR ADVANCE DEVIATION

1.Certainly YES 2.Rather YES 3.Perhaps YES 4.Perhaps NO 5.Rather NO 6.Certainly NO

#Certainly NO#

COOLING LIQUID FOUND IN OIL

1.Certainly YES 2.Rather YES 3.Perhaps YES 4.Perhaps NO 5.Rather NO 6.Certainly NO

#Certainly NO#

FUEL INJECTION PUMP FAILURE (70%): NON-UNIFORM FUEL SUPPLY, NON LEAK-PROOF OF CYLINDER AND PISTON, DAMAGE OF PISTON RING, BROKEN SPRING OF CYLINDER VALVE.

The system analysed these symptoms and began to provide treatment of the proposed diagnostic goal as shown in Figure 8. The consultation finished at this point after a successful session.

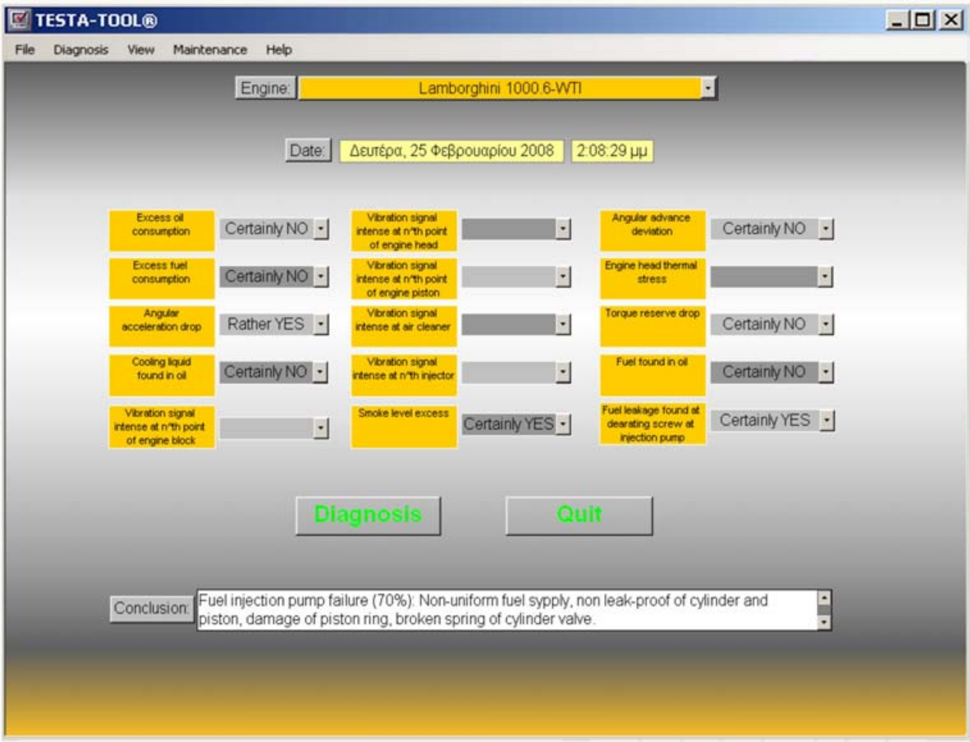


Figure 8: Demonstration of TESTA_TOOL diagnostic capabilities

Conclusions

This software tool (TESTA_TOOL) is designed to provide fault diagnosis and maintenance instructions, which will assist a user (engineer or mechanic) in discovering, isolating and correcting various technical problems that may arise in the diesel engines of heavy-duty machinery (as the self-propelled agricultural machinery). Software system architecture integrates knowledge database, inference engine with hypermedia system. The user interacts with the system through a hypermedia-based user interface. As illustrated, this new software tool assists engine diagnostician using the symptom lists, the diagnostic goals, the technical logbook and the reference manuals included in the system. Able to provide maintenance assistance in fixing engine malfunctions, it is expected to change the traditional techniques of engine diagnosis and maintenance. Apart from keeping and delivering a consistent diagnosis expertise of experienced mechanics, the system is also believed to contribute to safe operation and economy in maintenance work. Several test runs have been done and it has performed effectively. Our prospects for TESTA_TOOL are to expand its abilities in other related areas by adding more knowledge bases for other complex mechanical systems of self-propelled agricultural machinery, as transmission system, hydraulic mechanisms, etc.

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