Piotr **STRYJEK**
Tomasz **NIKISZ**
Krzysztof **SYKULSKI**
Michał **SOWA**

ELECTRONIC CONTROL SYSTEMS OF INTERNAL COMBUSTION ENGINES WITH RESPECT TO THE IMPLEMENTATION OF SPECIAL FUNCTIONS IN MILITARY VEHICLE

Abstract. Modern systems that control the operation of internal combustion engines provide many possibilities of shaping the characteristics of such engines. Additional special functions extend the technical capabilities of a vehicle, particularly under extreme conditions. Such functions also facilitate and improve the diagnostics of the engine and the power train. These systems have to be resistant to the increasingly advanced weapons which, for instance, make use of an electromagnetic impulse to destroy the electronics of enemy vehicles.

Keywords: military vehicles, internal combustion engines, control.

1. INTRODUCTION

Military vehicles should not only be characterized by reliability and ability to operate under harsh environmental conditions, but must also be able to continue operating with some of its components being damaged. In turn, the facility of repairing such components is of key importance for the rapid restoration of the combat capability of a vehicle.

Vehicles of today are being equipped with increasingly sophisticated electronic systems. This applies not only to weapon systems and specialized equipment, but also the control systems of internal combustion engines. There are now virtually no military vehicles in the market fitted with internal combustion engines, the control of which is be based entirely on mechanical controllers. Significant development of control systems based on electronic modules and used in civilian vehicles meant that it were these vehicles that often determined the state of the art in technology, rather than military vehicles, which until now have been considered to be more advanced. For this reason the solution applied in civilian vehicles, including the engine control systems, are often adapted for military purposes. The authors sought to analyze the risks, and also the advantages of modern electronic control systems of internal combustion engines in military vehicles.

Piotr **STRYJEK**, Michał **SOWA** – „OBRUM" sp. z o.o., Tomasz **NIKISZ**, Krzysztof **SYKULSKI** – ROSOMAK SA

2. SPECIAL FUNCTIONS IN THE CONTROL OF INTERNAL COMBUSTION ENGINES

Significant development of the electronic controls of internal combustion engines was dictated by several considerations. The major ones include:

- intention to increase the power to weight ratio of engines;
- need to attain the most advantageous torque/speed characteristics;
- intention to improve reliability of control systems;
- need to meet current exhaust gas emission standards.

All the above considerations have necessitated increasingly precise control of the combustion process. It was also necessary to take into account the conditions of combustion (temperature, pressure), including the results of the combustion process (lambda sensor, additional catalytic converter sensors, etc.). Limitations of mechanical controls make meeting the above and other diverse requirements impossible.

An example illustrating the growing requirements for engine control is the increasing stringency of exhaust gas emission limits. Fig. 1 shows how the toxic exhaust emission standards have tightened over the past two decades. Permissible emission levels of NO_x and HC have decreased by an order of magnitude, which already is difficult to meet by the leading vehicle manufacturers. It is important to point out that the presented changes relate to the standard that applies to non-road mobile machinery (the so-called STAGE standards) (introduced in Europe by Directive 97/68/EC), rather than the EURO standard (Directive 91/441/EC) which are applicable to the far the largest number of regular cars and trucks. Although the EURO 3 standard is still applicable to tactical and technical requirements for high mobility military vehicles or engineering vehicles, it seems more reasonable to consider the application of the standard with STAGE levels, where permissible levels of emissions in relation to kWh, which corresponds better to the actual conditions of vehicle operation.

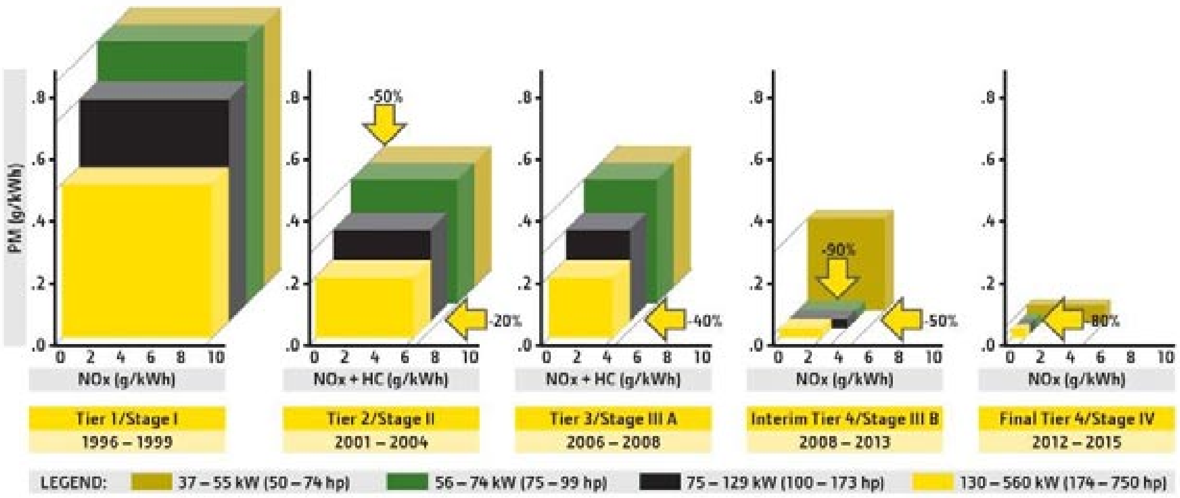
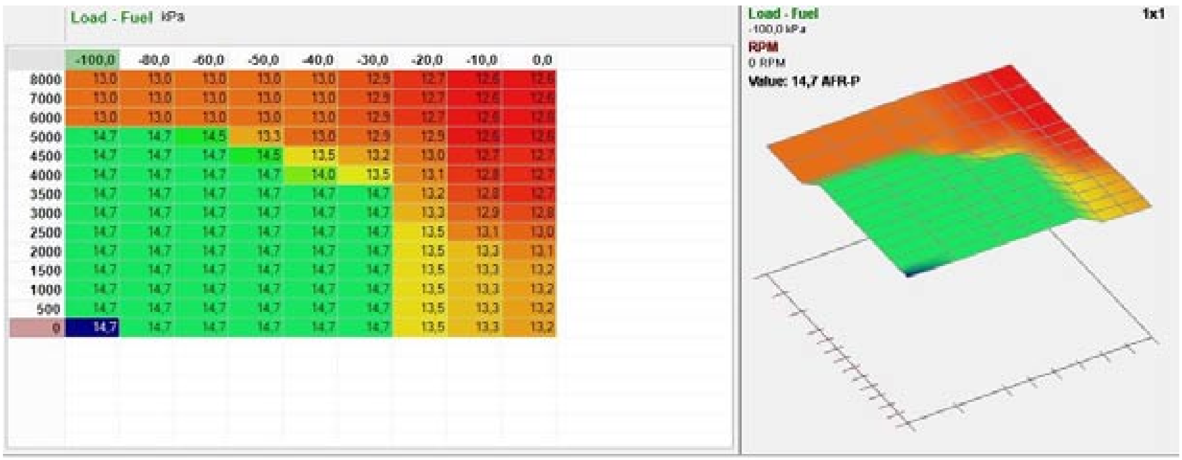


Fig. 1. Comparison of exhaust gas emission limits for utility vehicles between 1996 and 2015 [3]

The memories of engine and power train control systems store numerous data, based on which, depending on the information about the state of engine operation (data from sensors), various components are activated (injectors, valves, etc.). These are often visualized when making engine software changes in the form of graphic relationships called "maps". They are usually presented in a three-dimensional coordinate system, of which two dimensions are torque and rotational speed of the engine (field of engine operation), and the third dimension is the setting of the actuating unit of the system. These data are generally simple and smooth mathematical functions, with shape and form adopted experimentally. This is a significant advantage over mechanical or pneumatic controllers, that despite the often complicated structure and sensitivity of mechanical parts to wear, as well as the occurrence of backlash, allowed only an approximate realization of simple control functions (e.g. adjustment of the maximum amount of fuel or limitation of engine speed).

Electronic control systems allow multiple simultaneous functions, which on the one hand allow to maintain an appropriate level of pollutant emissions and fuel consumption, and on the other hand help develop appropriate nominal power or torque. An example of such an engine control map is shown in Fig. 2. The table on the left lists optimum values, on the right is the graphical representation of the area (this is a scan from a specialist program, where AFR means air to fuel ratio).



	-100,0	-80,0	-60,0	-50,0	-40,0	-30,0	-20,0	-10,0	0,0
8000	13,0	13,0	13,0	13,0	13,0	12,9	12,7	12,6	12,6
7000	13,0	13,0	13,0	13,0	13,0	12,9	12,7	12,6	12,6
6000	13,0	13,0	13,0	13,0	13,0	12,9	12,7	12,6	12,6
5000	14,7	14,7	14,5	13,3	13,0	12,9	12,9	12,6	12,6
4500	14,7	14,7	14,7	14,5	13,5	13,2	13,0	12,7	12,7
4000	14,7	14,7	14,7	14,7	14,0	13,5	13,1	12,8	12,7
3500	14,7	14,7	14,7	14,7	14,7	14,7	13,2	12,8	12,7
3000	14,7	14,7	14,7	14,7	14,7	14,7	13,3	12,9	12,8
2500	14,7	14,7	14,7	14,7	14,7	14,7	13,5	13,1	13,0
2000	14,7	14,7	14,7	14,7	14,7	14,7	13,5	13,3	13,1
1500	14,7	14,7	14,7	14,7	14,7	14,7	13,5	13,3	13,2
1000	14,7	14,7	14,7	14,7	14,7	14,7	13,5	13,3	13,2
500	14,7	14,7	14,7	14,7	14,7	14,7	13,5	13,3	13,2
0	14,7	14,7	14,7	14,7	14,7	14,7	13,5	13,3	13,2

Fig. 2. Characteristics of optimum air to fuel ratio for a spark ignition engine depending on load and speed of the engine (AFR = 14.7, corresponds to λ=1)

The data shown in Fig. 2 are for a spark ignition engine with a displacement volume of 2,000 cm^3 used in a passenger car. Analysis of these data indicates that the designer assumes engine operation with a stoichiometric mixture (i.e. air to fuel ratio (AFR) = 14.7, corresponding to $\lambda = 1$) only under a partial engine load. Within engine speed up to about 5,000 rpm and maximum engine load up to ca. 70% of maximum torque the controller ensures stoichiometric composition of the air-fuel mixture, which is required for proper operation of the three-way catalytic converter. Above this value the mixture is enriched, causing temporary increased level of harmful emissions, but at the same time the power attained is higher.

More advanced controls are used in sports cars, which can run under different power programs. A number of factors that affect the operation of the engine are then altered (change of map). Fig. 3 shows examples of control maps of ignition advance angle of the same engine of a sports car, capable of producing a maximum output of 206 kW and 309 kW, respectively.

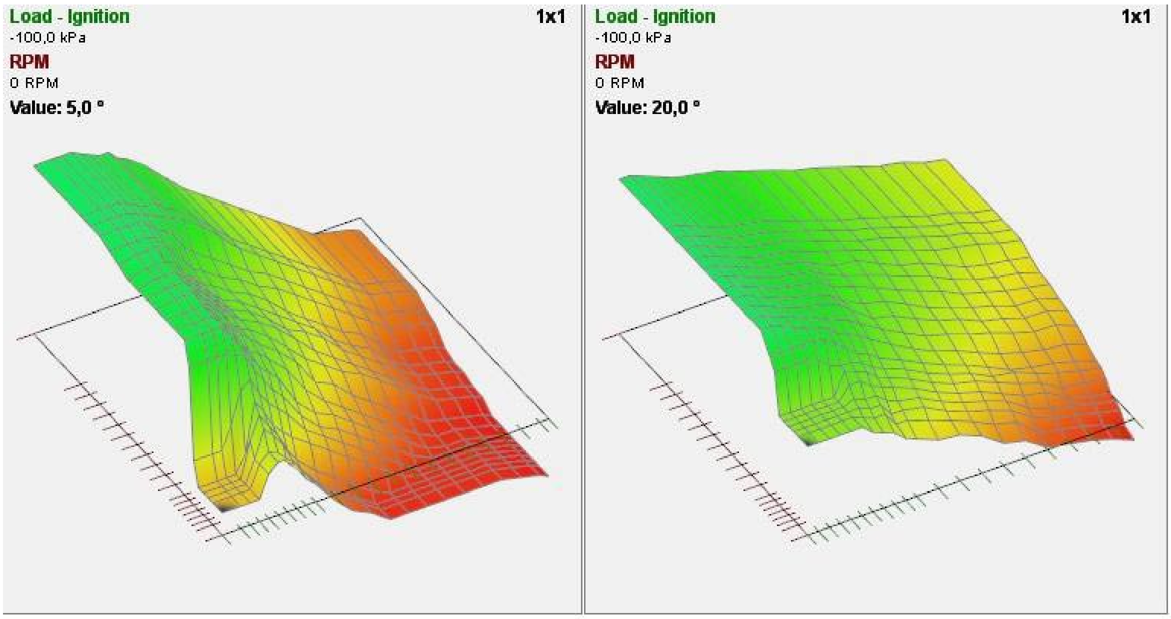


Fig. 3. Ignition advance angle vs. load and speed in a 4G63T engine with rated output of 206 kW and 309 kW

Solutions of this type are also used in military vehicles. An example is the Rosomak wheeled armoured personnel carrier (Fig. 3). It is powered by a six-cylinder diesel engine with a displacement volume of 11.7 dm^3. Depending on the operating conditions, this engine can operate in two power modes: combat or environmental.

In the combat mode the engine produces a maximum output of 360 kW and maximum torque of 1,970 Nm (at 1500 rpm). In the basic (environmental) mode, the output is reduced to 294 kW and torque to 1,670 Nm (at 1500 rpm) Switching between operating modes is effected by pressing an appropriate pushbutton.

Fig. 4. Rosomak armoured personnel carrier

The control system used enables increasing the power to weight ratio from ca. 13 kW/t to nearly 16 kW/t in combat version. Increasing the rated output of the engine by more than 20% translates into improved combat performance of the vehicle. In the basic mode a significant reduction in the level of pollutant emissions in the exhaust gas is achieved at the expense of a lower maximum output [1].

Apart from the possibility to set different engine operation control programs, it is also extremely important to ensure engine operation in case of partial damage of engine ancillaries. The present engine control systems make use of signals transmitted by dozens of sensors and actuators. While in civilian vehicles failure of even a less significant component can cause taking the vehicle out of service without any consequences, military vehicles in such circumstances should remain capable of withdrawing from the hazard area even at the risk of damage to the drive system (e.g. engine overheating after cooling system failure). Examples of these solutions of engine control in APC Rosomak are shown in Figs. 5 and 6. High coolant temperature warning functions are switched off, upper limits of coolant temperature are increased, and at the same time speed and maximum torque are limited, which translates into reduced release of heat. The vehicle is then able to get to a safe location at a lower speed.

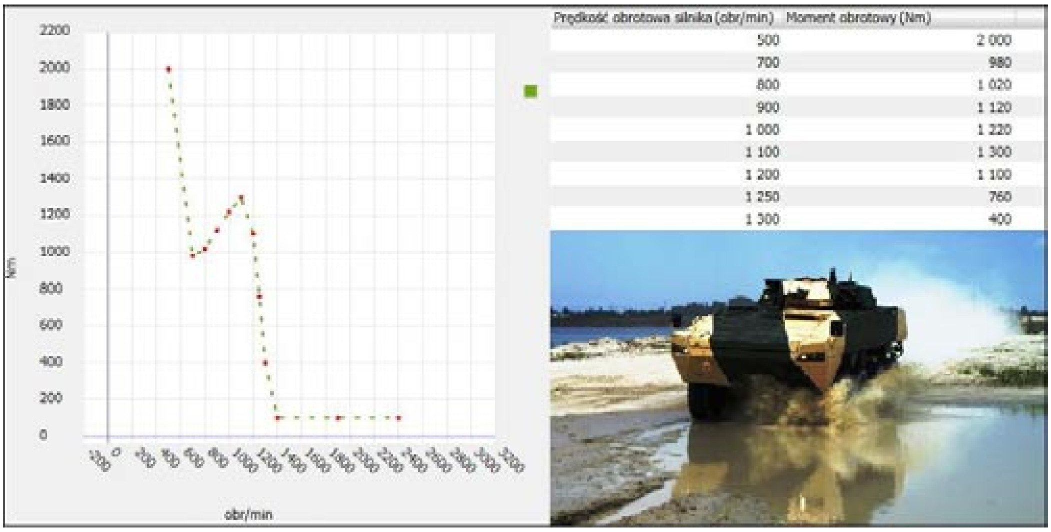


Fig. 5. Emergency torque limiting function

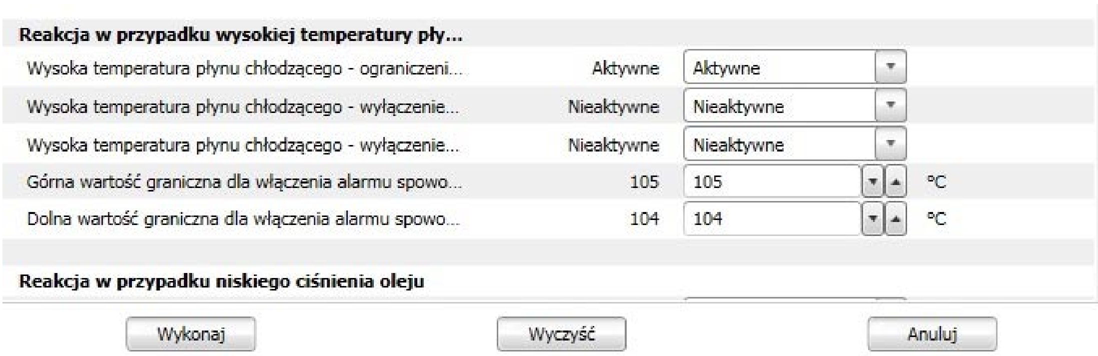


Fig. 6. Programming function for coolant temperature warning

Most of the safeguards of the vehicle are inconspicuous, but the manufacturer is able to set, in the maintenance mode, for instance, the alarm levels or levels of damage protection (e.g. engine torque limit values). This is important, as it allows to expand the tactical capabilities of vehicles, especially under combat conditions, where the safety of the crew is much more important than the integrity of equipment. Alterations of this type can only be made by highly specialized maintenance personnel.

3. SPECIAL FUNCTIONS IN ENGINE MAINTENANCE

Diagnostics of electronic control systems of engines are not limited to reading error messages saved in controller memories. The systems used nowadays are provided with powerful diagnostic tools which significantly speed up the troubleshooting process. To use these features, it is necessary to provide the maintenance teams with specialized diagnostic equipment and to have these teams properly trained. An example of such a mobile miltary vehicle repair station is a technical reconnaissance vehicle based on the Rosomak APC chassis (Fig. 7).

Fig. 7. Technical reconnaissance version (WRT) of the Rosomak APC [4]

Despite concerns of many modern vehicle users about the reliability of complex electronic systems, these systems also have a number of advantages that facilitate vehicle operation. Special features of such systems enable, for instance, performing a number of checks of the technical condition of the engine without the use of any additional equipment. One example is the measurement of the compression pressure in engine cylinders without the need for installing pressure gauges. Upon activating a special function by the diagnostic scan tool, instantaneous velocity of the piston is recorded. Similarly, on the basis of deviations in the control of the individual fuel injectors, it is possible to make initial diagnosis of the fuel system, without removing its individual components and without checking the injectors on specialized rigs [2]. This is particularly important when vehicle maintenance is done in the field and under combat conditions (e.g. during missions), where the vehicles and their engines may suffer many unpredicted damages. Then a failure can be promptly confirmed or ruled out. These functions are activated by the diagnostic scan tool and the whole diagnostic process is completed within a few minutes only.

The data stored in the controller on the conditions the vehicle has been operating in are also very useful. Based on these data the conditions under which the vehicle operated can be reproduced and the effect of these conditions on vehicle performance and engine wear can be determined. Fig. 9 shows, as an example, a graph of supercharging air and engine coolant temperature in a Rosomak APC during its operation. On the basis of the recorded data, the maintenance personnel can adjust the scope of maintenance and detect exceedance of limits that can cause damage during vehicle operation.

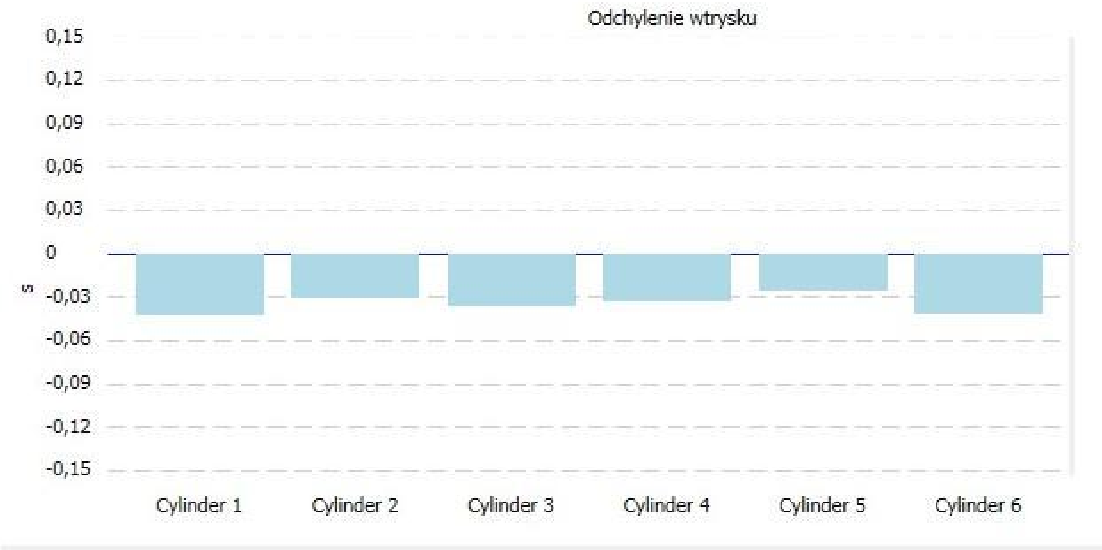


Fig. 8. Maintenance program display – fuel injection time deviations for individual cylinders

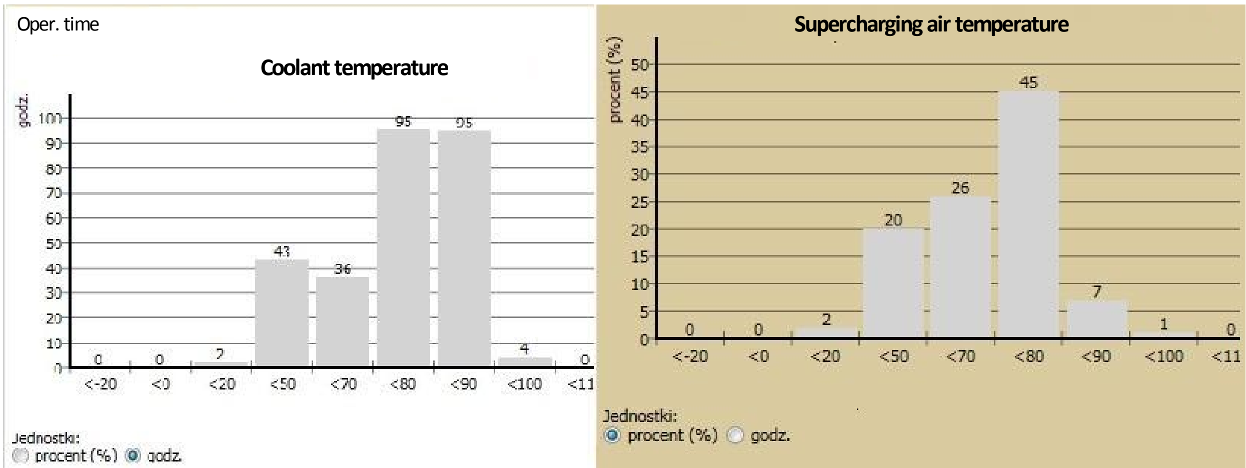


Fig. 9. Graphs stored in the memory of a controller of a Rosomak APC

A lot of diagnostic information is also provided by the oscilloscope graphic function integrated in the maintenance equipment. This feature is often overlooked by ther less experienced technicians. It displays the waveforms of signals from the various sensors within a defined period of time and enables comparison between the current values and reference waveforms (Fig. 10). Faulty operation of certain subsystems or components (e.g. a valve) is easily detected and then a decision on replacement can be taken without any further checks. This is very important when repairing a vehicle during a mission abroad, where access to specialized stations is limited.

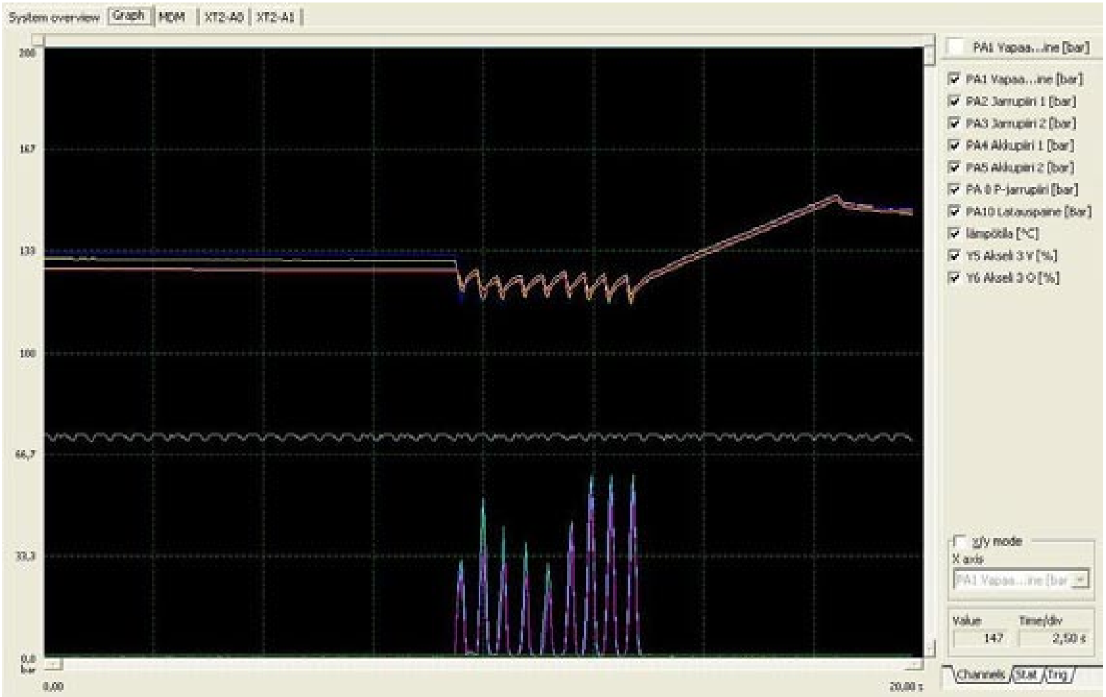


Fig. 10. Waveforms of signals from the brake system during testing

4. CONCLUSIONS

1. Modern systems that control the operation of internal combustion engines provide many possibilities of shaping the characteristics of such engines. This paper describes only some of the possibilities. The functions of electronic control systems allow to improve the diagnostics and to carry it out in a shorter time, which is of crucial importance under the conditions of a military mission. These solutions require a high level of expertise of the vehicle operating crews and maintenance teams.
2. The present military vehicles of high mobility are designed to be capable of operating with partial damage to the engine ancillaries and the vehicle (e.g. Rosomak APC) in line with defined procedures.
3. Requirements regarding the use and behaviour of military vehicles in a state of emergency are often not defined very accurately. This is particularly important at the time when increasingly advanced weapons are developed which, for instance, may make use of an electromagnetic impulse to destroy the electronics of enemy vehicles.

5. REFERENCES

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