EVALUATION OF ON-BOARD DIAGNOSTIC SYSTEMS IN CONTEMPORARY VEHICLES*

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Summary

In line with legal regulations, contemporary vehicles have to be equipped with electronic on-board diagnostic systems that conform to EOBD requirements. Those solutions feature diagnostic monitors that support self-testing of most systems in a vehicle. Technological progress and the uniformization of vehicle solutions have enabled users to monitor the systems on-line and modify their operating characteristics with the use of system control software.

This article discusses the threats posed by the implementation of uniform systems that support communication between external devices and vehicle systems. The overviewed solutions could compromise operating safety and significantly increase engine emissions – the main criterion for evaluating the technical condition of contemporary engines.

Keywords: mechanical vehicle, mechatronic system, CAN networks, on-board diagnostics.

OCENA FUNKCJONOWANIA SYSTEMU DIAGNOSTYKI POKŁADOWEJ WSPÓŁCZESNYCH POJAZDÓW SAMOCHODOWYCH

Streszczenie

Współczesne pojazdy samochodowe zgodnie z obowiązującymi przepisami obowiązkowo wyposażane są w elektroniczne systemy diagnostyki pokładowej zgodne z normą EOBD. Dzięki zastosowaniu tych rozwiązań pojawiły się nowe możliwości samodiagnostyki większości układów pojazdu poprzez monitory diagnostyczne zawarte w oprogramowaniu sterującym. Wraz z rozwojem i ujednoliceniem rozwiązań stosowanych w pojazdach pojawiły się również możliwości monitorowania on-line pracy poszczególnych układów, a także możliwości zmiany ich charakterystyk roboczych poprzez zmianę oprogramowania sterującego danym układem.

W niniejszym artykule przedstawiono zagrożenia wynikające z wprowadzenia ujednoliconych sposobów komunikacji zewnętrznych urządzeń z układami pojazdów, mogących wpływać zarówno na bezpieczeństwo eksploatacji jak i znaczny wzrost emisji spalin – główne kryterium oceny stanu technicznego współczesnych silników.

Słowa kluczowe: pojazd mechaniczny, układ mechatroniczny, sieć CAN, diagnostyka pokładowa.

1. INTRODUCTION

Contemporary vehicles are complex mechanical systems that are largely controlled by electronic (microprocessor) systems. The discussed systems, often referred to as mechatronic control systems, comprise:

- sensors which measure operating parameters (rotational speed, temperature, position) and transmit that information in the form of analog or digital electrical signals;
- controllers which process the received information based on the algorithms stored in memory and send control signals to actuators;
- actuators which analyze the received control signal to direct the activities of an actuating element, e.g. solenoid valve, servomotor or stepper motor.

In comparison with mechanical systems, electronically controlled systems deliver much greater control accuracy due to an absence of mechanical connections between measuring and actuating systems. Electronically controlled systems also analyze a greater number of control signals to produce output values. Closed-loop control systems are used to guarantee that actuating elements are controlled with a high degree of accuracy (Fig. 1) [5].

Microprocessor control in vehicles and machines creates extensive access to information processed by the controller. Such information is used to control a given system and regulate the activities of other systems. Data that are registered and processed by the controller are also used by other control systems to evaluate the technical condition of vehicle parts and generate information for the user [4, 5, 7, 8].

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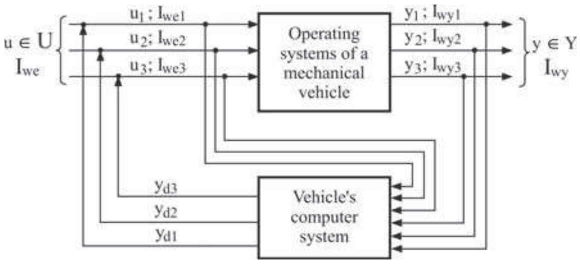

Fig. 1. System control in contemporary mechanical vehicles: $u \in U$ – set of input signals, I_{in} – input data, $y \in Y$ – set of output signals, I_{out} – output data, $y_i(I_{out})$ – task progress information, y_{di} – control signals

Contemporary vehicles are standard equipped with on-board diagnostic systems. The current market standard is EOBD (European On Board Diagnostics) which dictates the rules for communication between external diagnostic devices and vehicle controllers [4].

2. EOBD (OBD II) STANDARD

In the late 20th century, the rapid development of microprocessor controlled systems prompted the development of new standards for communication between control systems and diagnostic devices. The OBD II standard was developed in the US in 1996 to enable the use of several communication protocols between diagnostic devices and the vehicle. The European equivalent of OBD II is the EOBD (European On-Board Diagnostics) standard. It was introduced in Europe in 2000, and initially, it applied only to vehicles with petrol engines. In 2003, the standard became mandatory for diesel engines as well as vehicles powered by LPG [4, 7, 8].

The following stage of development of electronic control systems witnessed the implementation of the CAN (Controller Area Network) standard of communication with external diagnostic devices [2, 4, 8, 9]. An unquestioned advantage of the EOBD standard was that it introduced uniformity into communication with diagnostic devices as well as uniform norms for coding errors that affect the safety of vehicle users and the level of toxic pollutants released into ambient air [4]. The replacement of mechanical control systems with electronically controlled devices improved the vehicle's operating characteristics and enabled simple monitoring of basic working parameters, including operating temperature and voltage at battery terminal clamps (Fig. 2).

Fig. 2. Display window with information about engine temperature and battery voltage

Contemporary mechatronic systems rely on monitors that control the continuity of electric systems and values registered by various system components. Those solutions provide users with information about other events that affect driving safety, such as failure of the vehicle's lighting system (Fig. 3) [2, 4, 8, 9].

Fig. 3. Diagnostic message informing the user about rear lamp circuit failure

3. CONTROL SYSTEMS IN MECHANICAL VEHICLES

Microprocessor controllers are the backbone of every modern control system. The controller processes signals from sensors that measure input values, data transmitted by other systems as well as information about the outputs supplied by control and measuring devices. Based on the above data, the controller makes decisions to change working parameters.

Contemporary vehicles and machines are complex mechatronic systems which generally operate as part of a global electronic platform that monitors all electronically controlled systems in a vehicle. This solution supports dispersed control of all systems where every controller performs its functions independently and, if required, exchanges information with the controllers of other systems.

The vast majority of corporations manufacturing vehicles and machines (construction, road and farming equipment) operate their own platforms for managing electronic control systems. Those platforms have uniform electronic system architecture which, subject to the vehicle's or machine's equipment standards, differs with regard to the number of applied modules, systems and their configurations. Most vehicles have uniform bus architecture which relies on CAN and other sub-networks. In this approach, sub-networks are often other CAN networks with different data transmission speeds, as well as other types of networks, such as LIN (Local Interconnect Network) which controls comfort and convenience applications in vehicles [2, 8, 9]. The configuration of an on-board computer system in a contemporary vehicle is illustrated in Figure 4.

A diagnostic connection port (DLC – Data Link Connector) is an important part of a vehicle's electronic bus system. In addition to diagnosing the vehicle's systems, DLC can modify the existing software if errors are detected during the operation of a given group of vehicles, and it can block selected functions (e.g. by limiting the engine's rotational speed when vehicles are transported from the manufacturing plant to the dealer's facility). In most cases, mechatronic systems have adaptive algorithms which respond to the wear of various elements and adapt the system to new requirements. Despite the obvious advantages that follow from adapting the system to the technical condition of its constituent elements, this solution can also have negative consequences by concealing errors in the adaptation process [1, 3].

4. THREATS POSED BY ELECTRONIC CONTROL SYSTEMS

The introduction of uniform standards of communication between external devices and on-board microprocessor-based systems has created new, relatively simple options for monitoring the operation of control systems in vehicles. Selected diagnostic functions can be switched off by the on-board computer, such as DPF (Diesel Particulate Filter), a device designed to remove particulate matter from the exhaust gas of a diesel engine. When the filter is physically removed, the control unit switches the engine to emergency mode. Many service providers on the auto-motive market offer to disable the filter in the software that monitors engine operation. The above significantly increases pollutant emissions into ambient air, and the error is not recognized by the monitoring system. Other standard systems in a vehicle can be disabled in a similar manner, and the user may not even be aware of the above.

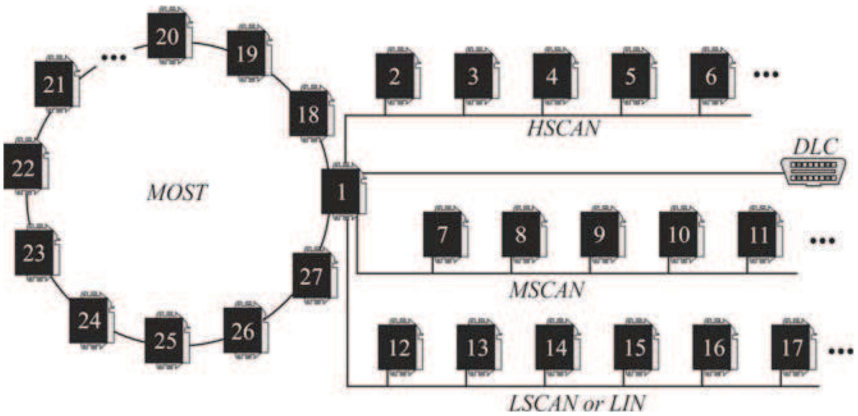

Fig. 4. Block diagram of a vehicle's network: 1 – main module/geteway, 2 – engine control module, 3 – ABS, 4 – transmission control module, 5 – yaw rate sensor which measures lateral and longitudinal acceleration, 6 – electro-hydraulic power steering, 7 – body control module, 8 – instrument panel cluster, 9 – parking assistance system module, 10 – sensing and diagnostic module for air bag control, 11 – underhood electrical center, 12 – passenger door module, 13 – sun roof module, 14 – auxiliary heating, 16 – driver door module, 17 – driver seat module, 18 – radio, 19 – CD/DVD, 20 – CD changer, 21 – phone, 22 – navigation GPS, 23 – display, 24 – tuner TV, 26 – control panel, 27 – USB port, *DLC* – Data Link Connector, *HSCAN* – High-Speed Controller Area Network, *MSCAN* – Mid-Speed Controller Area Network, *LSCAN* – How-Speed Controller Area Network, *LIN* – Local Interconnect Network, *MOST* – network Media Oriented Systems Transport

Chiptuning is yet another popular manipulation of the engine's microprocessor controlled function. Control software is modified to change the system's working parameters, and this procedure is often performed to modify the engine's power characteristics and torque. The major systems of every vehicle, including the engine and the transmission system, operate based on fixed control algorithms, and the only differences result from changes in the value of control parameters in various memory areas. Any change of values registered in this area of controller memory modifies control values and changes the operating characteristics of the relevant system. Controller memory also features different value limiters which can be changed to boost a vehicle's performance or speed. Vehicle controllers are generally provided with tamper protection systems that rely on checksums, but tuning applications can be used to introduce the desired changes and prevent the system from spotting those modifications.

Communication interfaces and software available on the market provide users with virtually unlimited possibilities of configuring the operating parameters of their vehicles, in particular engine performance. Data describing engine performance and the correlations between engine parts are usually stored in the form of maps which are automatically identified by specialist software (Fig. 5) [6]. The data can be easily manipulated by editing a memory map or changing the values in the memory map table. The widespread availability of cheap and easy-to-use software for modifying controller operations can lead to structural damage of the vehicle and its components (Fig. 6). Alterations of the engine's control settings can also increase pollutant emissions into ambient air.

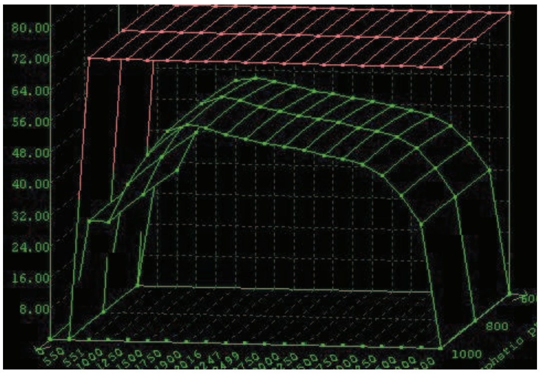

Fig. 5. A memory map stored in the controller to limit engine torque

Fig. 6. A piston damaged (burnt out) by an incorrect modification of the engine's control software

Some car workshops modify engine control software to "repair" errors that are reported during vehicle operation. This practice is popularly applied to fix a common error in older cars with diesel engines. Many users find that a warm diesel engine is difficult to start, whereas no such problems are reported when the engine is cold. The above results from the wear of the starter (high internal resistance) or low battery voltage. In diesel engines, the injected fuel dose is determined based on a memory map stored in controller memory (Table 1). As shown in Table 1, at engine temperatures higher than 20ºC and rotational speed below 200 rpm, the required fuel dose is 0. Therefore, the engine cannot be started if the required rotational speed is not achieved. The presented data indicate that for an engine to be started at higher temperatures, higher rotational speed is initially required, which is difficult to achieve with a damaged starter. When the values in the marked area of the memory map are modified, fuel can be injected at lower rotational speed, thus facilitating engine start-up.

Table 1

Memory map describing the fuel injection dose subject to the engine's temperature and rotational speed

		Engine temperature [°C]								
		-30	-10	0	15	20	40	70	85	100
engine speed [rpm]	0	49	45	33	0	0	0	0	0	0
	200	49	45	33	29	0	0	0	0	0
	250	49	45	33	29	27	21	0	0	0
	280	49	45	33	29	27	24	22	21	19
	756	49	44	33	29	27	24	22	21	19
	1008	48	43	32	27	25	24	22	21	19
	1260	44	39	29	23	22	23	17	16	19
	1554	41	36	22	18	16	19	10	9	6

It should be noted that the described relationship contradicts the general rule for combustion engines. Mechanically controlled engines are always easier to start when warm. Therefore, the introduction of electronic control systems could lead to an incorrect diagnosis of errors when the condition-symptom method is used.

The characteristics of an electronically controlled system can also be changed by modifying sensor parameters. As a result of the above, the control system is "fooled" by falsified input settings. System modification leads to changes in output values and, consequently, working parameters.

System parameters can also be changed with the use of tuning boxes which are ready-made solutions available on the market. When connected to the control system, they can boost engine power (PowerBox) or lower fuel consumption (Ecobox). In older-generation systems, the signal transmitted to the controller was reinforced or weakened relative to the signal emitted by the sensor. In advanced control systems, when the set range of signal values is exceeded, the system operates outside of the programmed range, and the error is detected by diagnostic monitors of the respective system. The latest tuning boxes are programmable, and the signal produced based on the sensor-generated signal can be freely modified. The characteristics of a programmable box is presented in Figure 7. The use of a box with similar characteristics eliminates the danger that extreme signal values will be exceeded. The introduced changes cannot be easily identified by the control system, and they can modify operating parameters at average load values. Fuel pressure is increased when a box component is inserted in a common rail engine between the fuel pressure regulator in the fuel rail and the controller. At constant injection pulse values, increased fuel system pressure results in higher engine power.

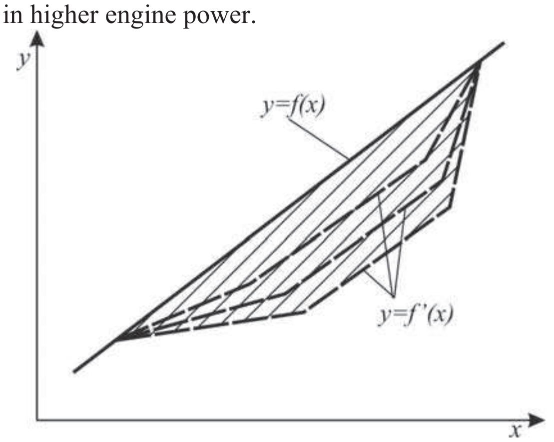

Fig. 7. Characteristics of a programmable box: $y=f(x)$ – original characteristics of signal y relative to parameter x, $y=f'(x)$ – programmable functions, shaded area is the programmable area of changes

5. CONCLUSIONS

Contemporary vehicle control systems feature advanced on-board diagnostic capabilities that monitor the functioning of the vehicle's major systems. Following the standardization of control systems and protocols for communication with external devices, those systems can be easily modified or even deactivated. The resulting changes may not be identified by on-board or external diagnostic systems. Under current law, most manipulations of control system settings cannot be detected during periodic vehicle inspections.

Changes in the operation of car systems may be difficult to identify because they require comprehensive tests covering the entire vehicle. The latest tuning solutions can both activate and deactivate a vehicle's control systems with the use of a remote control unit. Selected solutions feature engine control systems with two independent control algorithms for economy and high-speed driving. In many cases, only one engine control program is modified, which makes it even more difficult to identify the changes.

The solutions for modifying mechatronic systems are increasingly advanced, and workshops performing periodic car inspections are practically unable to diagnose the introduced alterations. According to the suppliers, tune-up applications that modify vehicle and engine operating parameters can be easily installed even in brand-new cars without the danger of voiding the manufacturer's warranty, provided that the device is removed prior to a visit in the dealer's service station.

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