ASPECTS CONCERNING THE ELECTRONIC CONTROL OF INTERNAL COMBUSTION ENGINES USING ONBOARD DIAGNOSIS

Vasile TÎNJALĂ[1], Corneliu NEAGU[2], Sergiu TONOIU[3]

Lucrarea subliniază faptul că dezvoltarea tehnică a automobilului a dus la apariția de proceduri şi aparatură de diagnosticare moderne, precum şi softuri de interpretare a datelor prelevate, atât pentru motoarele cu ardere internă, cât şi pentru celelalte sisteme şi mecanisme din compunerea automobilului. Mijloacele instalate la bordul autovehiculelor pentru controlul funcționării ansamblelor şi subansamblelor autovehiculului au devenit multifuncționale în sensul că ele oferă în acelaşi timp şi informații legate de diagnosticare. Diagnosticarea la bord, implementată cu pregnanță la autovehiculele cu motoare cu aprindere prin scânteie, capătă o răspândire largă şi la cele echipate cu motoare cu aprindere prin comprimare. Datorită existenței controlului electronic care beneficiază de informațiile furnizate de traductoarele încorporate, noile tehnologii oferă facilități de funcționare normală, cu satisfacerea cerințelor impuse, chiar şi în situația unor imprecizii de fabricație, montaj, reglaj şi întreținere. Scopul diagnosticării la bord este deci de a atenționa conducătorul auto asupra prezenței unei defecțiuni în sistemul de control al emisiilor şi de a identifica locația defecțiunii.

This paper highlights the fact that the technical development of automobiles has led to the apparition of procedures and devices for modern diagnosis as well as interpretation software programs for gathering data, both for engines with internal combustion and for the other systems and mechanisms which make up a vehicle. The devices installed onboard in order to control the function of assembles and sub-assembles have become multifunctional, offering also diagnosis information. Onboard diagnosis, mainly implemented on spark ignition engines, is broadly used for those equipped with diesel engine. Due to the electronic control of incorporated transducers, modern technologies provide accurate and adequate working conditions, even under conditions of lack of manufacturing, mounting, tuning and maintenance accuracy. The goal of the On-Board Diagnostics is to alert the driver when a malfunction of the emission control system appears and to identify the source of the problem.

Keywords: on board diagnosis, emission control, integrated design process, model based vehicle diagnosis

[1] Eng., PhD Candidate, Dept. of Machine Manufacturing Technology, University POLITEHNICA of Bucharest, Romania

[2] Professor, Dept. of Machine Manufacturing Technology, University POLITEHNICA of Bucharest, Romania

[3] Assoc. Professor, Dept. of Machine Manufacturing Technology, University POLITEHNICA of Bucharest, Romania, e-mail: sergiu_ton@yahoo.com

1. Introduction

In order to achieve comfortable and adequate living conditions, standard functioning parameters were imposed to all polluting agents (automobiles, concrete factories and so on). On-board Diagnostics Regulations in the world for light and medium duty vehicles (internal combustion engines) are introduced to implement the air quality standards, and the first country who promoted that was the U.S.A. The First major Clean Air Act was adopted by the Congress in 1970. Congress established the Environmental Protection Agency (EPA) with the overall responsibility of regulating motor vehicle pollution to the atmosphere. Congress also identified the Inspection and Maintenance (I/M) programs as an alternative for improving the air quality. On Board Diagnostics (OBD) systems were designed to maintain low-emissions of in-use vehicles, including light and medium duty vehicles. OBD II is the next generation OBD system of vehicles designed to reduce the time between occurrence of the malfunction and its detection and repair, with the objective to reduce hydrocarbon (HC) emissions caused by malfunction of the vehicle's emission control system. [1]

OBD II [2, 3] will also minimize the damage to other vehicle systems or components. Such diagnostic systems are implemented by incorporating additional software and hardware in the vehicle electronics system to collect and analyze data already available to the on-board computer, and monitoring the entire emission control system. The emissions are measured using instruments such as Dynamometer test, Hydro Carbons Analyzer, and other analyzers. Standards have been set for the vehicle half-life (5 years or 50000 miles) and full cycle (10 years or 100000 miles) [4]. The following standards are enforced 100% after 1996: HC 0.31 gms/mile, CO 4.20 gms/mile, NOx 0.60 gms/mile (non-diesel), 1.25 gms/mile (diesel). In Europe, since October 2008, Euro 5 regulations have been applied, with the following indicators: HC 0.46 g/kWh, CO 1.5 g/kWh, NOx 2.0 g/kWh.

In addition, the OBD II system should illuminate the Malfunction Indicator Light (MIL) and store the Trouble Code in the computer memory for all malfunctions that are contributing to increased HC emissions. The powertrain is controlled by the Powertrain Control Module (PCM) or Electronic Control Module (ECM) computer to deliver the required torque to the vehicle requested by the driver and to limit the vehicle emissions to the required minimum to meet EPA regulations.

2. Applications of onboard diagnosis for automobiles

For the diagnosis procedures on gasoline injection engines we used the Daewoo Cielo Executive automobile, which had a 1.5 L SOHC engine and satisfied Euro 3 emission regulations. [6] The motorcar was fabricated in 2005 and had a mileage of 48500 km. The data processing was carried out using MATLAB programming language [7] and Microsoft Office (EXCEL, WORD) applications. The methodology of the experimental tests on the automobile resides in the variation of pressure levels that occur in the intake manifold in order to induce controlled malfunctions in some of the sensors.

The assessment of pressure losses was performed on a stand with four rolls. The front wheels of the car ran freely and the automobile was not permitted to shift laterally with the help of the parking brake. The progression of the car with constant speed and load was simulated in this way: the load (between 3.1% and 10.9%) resided in the vehicles own weight and in the friction of the roll bearings, and the speed was maintained constant by switching the speed gear successively from the first gear through the third gear and by keeping disengaged, at the same time, the acceleration paddle. Nozzles of 0 mm, 2 mm, 3 mm, 4 mm, 5 mm and 6 mm (Fig. 1b, second position) were installed on the intake manifold. In order to be able to install the nozzles, the pipe that supplies the assisted braking and the characteristic reduction device were uninstalled, and another reduction device was assembled. The above mentioned nozzles were subsequently installed in the new reduction device (Fig. 1a, second position).

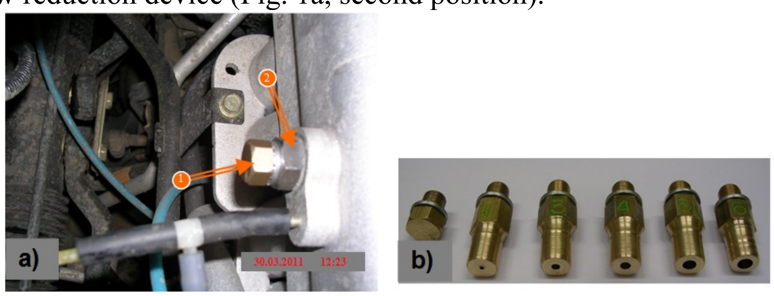

Fig. 1. Simulated (controlled) malfunction caused by pressure losses of the intake manifold
a) placement of the nozzle b) experimental nozzles

The 0 mm nozzle (fig. 1a, first position) required the normal functioning of the engine, the pressure losses did not occur when using this nozzle and the purpose was to create a standard of measurement to which other tests should be compared. Pressure losses recorded in the intake manifold were not continuous. The nozzles were blocked and the decrease of the pressure levels took place every 50 values recorded by the Scan 100 device. Twenty experimental tests were performed for this test. Each nozzle underwent 5 tests, i.e.: one at the base level of engine revolution, one in the first gear, one in the second gear and one in the third gear.

The other testing model was also aimed at the pressure losses recorded in the intake manifold, and the nozzles were installed on the same reduction customized for the intake manifold. This time, the experimental tests were conducted on a test site, in a dynamic manner, and the car was driven according to an a few urban-specific parameters. The first part of each test (50 values) took place under a constant speed (30 km/h) and without pressure losses. Afterwards, upon recording 100 values, the speed was changed randomly and no pressure losses were induced. During the last part of the test (26 values), pressure losses were ceased and the speed was, again, randomly selected.

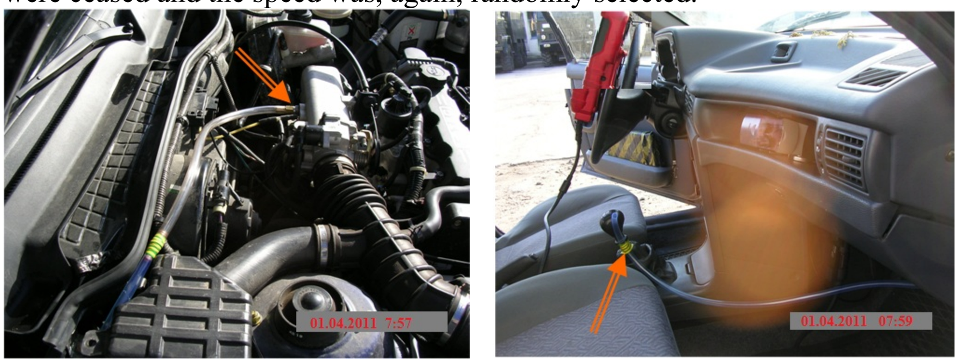

Fig. 2. Preparing the automobile for testing in a dynamic regime

In order to control pressure losses, a flexible pipe (a hose) has been mounted on the nozzles. This pipe is within the driver's reach by hardening toward the gear shift (Fig. 2).

For the third type of tests, pressure losses from the intake collector have been traced in the same way. The only difference from tests of Type 2 was that the first 50 values were recorded at non-constant speeds, and the car was moving at higher speeds. As it can be inferred, for this kind of tests, pressure losses from all six nozzles were recorded from value 51 to value 150.

Causing engine faults in the automobile was the reason for carrying out Type 4 tests. These were performed in a testing range, dynamically, at random speeds. Three sensors where chosen whose failure was considered to be significant: the *oxygen sensor (*O_2*), the position sensor for the throttle shutter (TPS) and the air pressure sensor within the intake manifold (MAP)*. Given that each of these sensors has a power supply circuit (+5 volts) controlled by the ECM, a response circuit and a mass circuit (which is common to more circuits, in the case of TPS and MAP sensors, and is absent in the oxygen sensor), we used an assembly consisting of a „controller” with three tilting switches (one for each separate circuit) and six conductors. One test consisted of interrupting one, two or all three circuits of a sensor and observing the effects of each interruption. The discontinuing of circuits has been performed for 100 registered values, after the automobile ran for part of the test (50 values) without showing malfunctions; for the last portion of the test (26 values), one or more circuits have been (re)closed.

It should be noted that after each test of this type, a mandatory check of the fault code/codes on the vehicle's display has been performed. The fault codes have been recorded and then deleted so as not to influence the results of further tests.

3. The obtained results

Given the objectives of the present study, the experimental research focused on five types of experimental evidence: the first three types follow the influence of pressure losses in the intake manifold on other engine parameters; Type 4 evidence is obtained from simulations of engine operation with a few faulty sensors. In order to obtain mathematical models of faultless engine operation, a set of dynamic tests have been performed on dry pavement, as shown in Table 1.

Table 1

Experimental evidence

<table>
<tr><th>TYPE OF EVIDENCE</th><th>TEST SITE</th><th colspan="2">FAULT TYPE</th><th colspan="2">NUMBER OF TESTS</th><th>EVIDENCE NOTATION</th></tr>
<tr><td rowspan="6">TYPE 1</td><td rowspan="6">Test stand</td><td rowspan="6">Pressure losses, intake</td><td>0 mm nozzle</td><td>5</td><td rowspan="6">30</td><td>D0R01-D0v3</td></tr>
<tr><td>2 mm nozzle</td><td>5</td><td>D2R01-D2v3</td></tr>
<tr><td>3 mm nozzle</td><td>5</td><td>D3R01-D3v3</td></tr>
<tr><td>4 mm nozzle</td><td>5</td><td>D4R01-D4v3</td></tr>
<tr><td>5 mm nozzle</td><td>5</td><td>D5R01-D5v3</td></tr>
<tr><td>6 mm nozzle</td><td>5</td><td>D6R01-D6v3</td></tr>
<tr><td>TYPE 2</td><td>Test range</td><td colspan="2">Pressure losses, intake</td><td colspan="2">10</td><td>D0P1-D6P2</td></tr>
<tr><td>TYPE 3</td><td>Test range</td><td colspan="2">Pressure losses, intake</td><td colspan="2">15</td><td>VD0P1-VD6P2</td></tr>
<tr><td rowspan="3">TYPE 4</td><td rowspan="3">Test range</td><td rowspan="3">Sensor faults</td><td>MAP</td><td colspan="2">10</td><td>MAP1-MAP123P2</td></tr>
<tr><td>TPS</td><td colspan="2">8</td><td>TPS1P1-TPS123</td></tr>
<tr><td>O2</td><td colspan="2">8</td><td>SO1-SO2P3</td></tr>
<tr><td>TYPE 5</td><td>Urban; dry pavement</td><td colspan="2">Faultless</td><td colspan="2">15</td><td>FD1-FD15</td></tr>
</table>

Fig. 3 shows four of the parameters recorded in extra-urban driving conditions, with the engine operating without any faults. Thus, for a start-up time approaching t_{d100} (approximately 10 seconds) and the resulting movement speed (Fig. 3d), the value of the shutter position and that of air pressure in the intake manifold are frequently at their maximum value, as it is normally expected when the two sensors are working at optimum parameters (faultlessly).

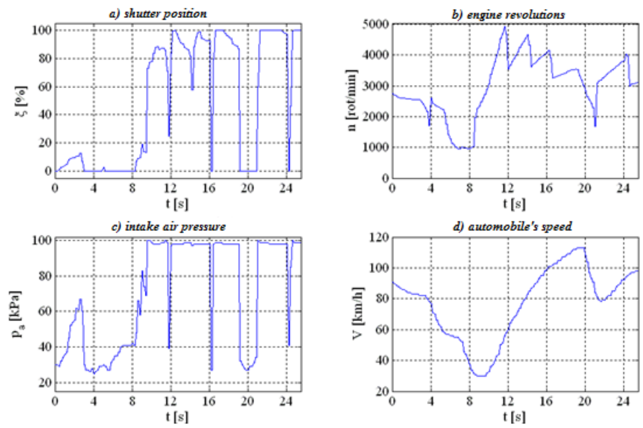

Fig. 3. Parameters recorded for faultless functioning of the engine (FD7 test)

Fig. 4 shows the influence of pressure loss in the intake manifold on the engine's idle rotation speed. The position of the gear shift is, successively, neutral (a), 1st gear (b), 2nd gear (c), 3rd gear (d). The tests were performed on a test stand.

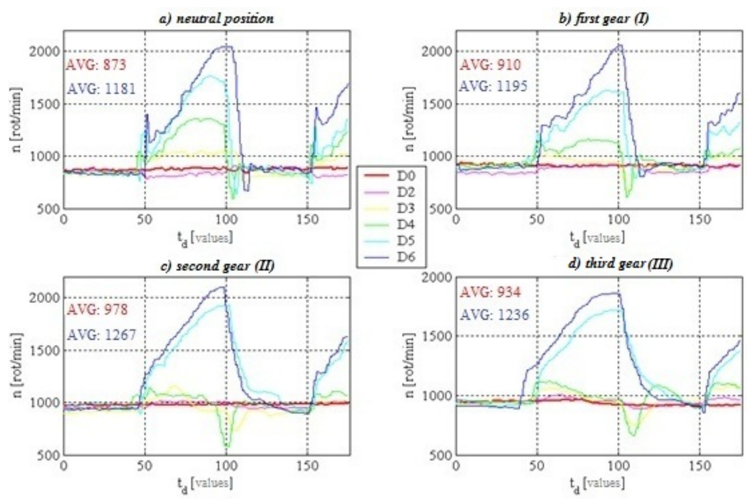

Fig. 4. Influence of pressure loss on the engine's rotation speed

All six nozzles were used, labeled from D0 to D6. D0 (red color) represents the engine running without losses, practically without any faults and without use of the throttle pedal. As it can be seen, pressure losses result in an average increase of 300 rpm in the engine's idle rotation speed, reaching up to 2000 rpm in case of the 6mm nozzle (D6, blue color).

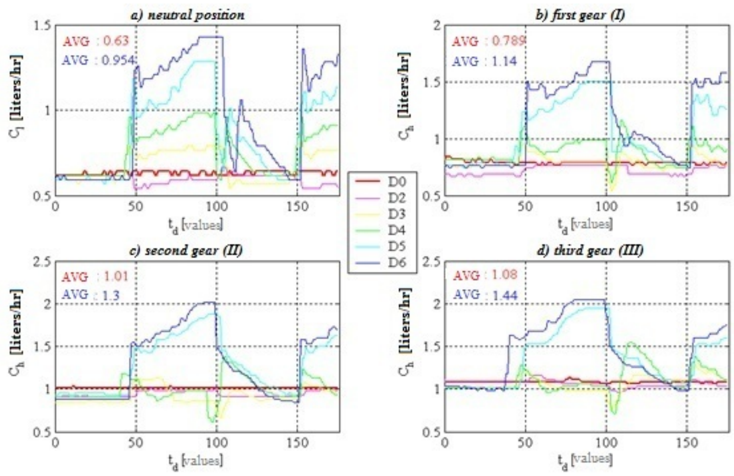

Fig. 5. Influence of pressure losses on fuel consumption

Important parameters of automobile performance such as torque, effective power or fuel consumption cannot be directly measured by the utilized means of testing. The hourly fuel consumption graph shown in Figure 5 indicates that this parameter changes upon the occurrence of pressure losses in the intake manifold. The increase in fuel consumption can even exceed 100% for the 6 mm nozzle (D6).

While carrying out experimental tests, our aim was to cause malfunctions that would simulate the faulty functioning of the engine, which should be easily identified both by the driver, thanks to the MIL lamp lighting up, and by the diagnostic equipment, when it is available.

It must be mentioned that, in reality, there are more factors which may cause the ignition of the MIL lamp on board. The producer suggests that, in any such case, the driver should stop the engine and ask for assistance from a service unit. [8]

So as not to damage the car's electrical circuit, each sensor's circuits have been identified (in the diagram provided by the producer) and their interruption has been performed in a controlled manner. Thus, Figure 6 presents the results of ongoing disruption of the three circuits of the absolute pressure sensor within the intake manifold (MAP).

As a consequence of the interruption of the three circuits, while the test was being performed, the MIL lamp (Fig. 6a) ignited on board. The light stayed on until the fault was removed from the on-board computer's memory using the diagnostic tool.

Fig .6. Detection of the malfunction

a) MAP sensor malfunction b) MAP123P2 test

Since the interruption of the circuits was performed just for 100 registered values (approx. 22 seconds), the vehicle's on-board computer registered two fault codes (Fig. 6b): a current code, P1107 – intermittent low voltage in the absolute pressure sensor within the intake manifold – and the historic code P0107: low voltage in the absolute pressure sensor within the intake manifold.

In order to erase the faults from the on-board computer's memory, the option to „Erase malfunction codes" was selected from the menu of the Scan 100 diagnostic tool. Following the erasure operation, the MIL lamp on board the vehicle was no longer on.

Similarly, results of the interruption of circuits 1 and 2 (mass circuit and +5 volt circuit, respectively) of the throttle position sensor (TPS) are shown in Fig. 7.

a) TPS sensor malfunction b) TPS12 test

Fig. 7: Detection of the malfunction

This time, two different codes were recorded (Fig. 7b): P1122 – intermittent low voltage of the throttle position sensor – and P0122 – low voltage. Given the examples shown, it can be concluded that the vehicle's onboard diagnostics proves to be a modern and highly efficient method. Table no. 2 presents the results of on-board diagnostics for experiments of this type.

Table 2

Malfunction codes reported by the vehicle's on-board computer

Sensor	Interrupted circuit	Test	On-board lamp ignited? (MIL)	Malfunction code obtained (Scan 100)
Throttle shutter position (TPS)	1	TPS1P1; TPS1P2	No	None
	2	TPS2	Yes	P0122; P1122
	3	TPS3	Yes	P0122; P1122
	1 and 2	TPS12	Yes	P0122; P1122
	1 and 3	TPS13	Yes	P0122; P1122
	2 and 3	TPS23	Yes	P0122; P1122
	1, 2 and 3	TPS123	Yes	P0122; P1122
Intake manifold absolute pressure (MAP)	1	MAP1	No	No
	2	MAP2	Yes	P0107; P1107
	3	MAP3	Yes	P0107; P1107
	1 and 2	MAP12P1; MAP12P2	Yes	P0107; P1107
	1 and 3	MAP13P1; MAP13P2	Yes	P0107; P1107
	2 and 3	MAP23	Yes	P0107; P1107
	1, 2 and 3	MAP123P1; MAP123P2	Yes	P0107; P1107
λ sensor (O_2)	1	SO1	No	No
	2	SO2P1; SO2P2; SO2P3	No	No
	1 and 2	SO12P1; SO12P2; SO12P3	No	No

4. Conclusions

The study highlights the influence of pressure losses in the intake manifold on other parameters (engine rotation speed, injection time, hourly fuel consumption), as well as the malfunctioning of sensors (pressure, throttle position, oxygen) upon controlled discontinuation of certain circuits.

First and foremost the present study shows a set of conclusions regarding the influence of pressure loss from the intake manifold (manifested through indistinguishable small cracks or larger ones) on certain parameters, such as:

- The engine rotation, which increases from 870 rotations per minute to 2000-2500 rot/min due to major pressure loss that took place for about 15 seconds (the nozzle with a 6 mm diameter) while the engine is kept idling and at a constant 3% load (Fig. 4a); the speed of the idling engine is less accentuated when the load reaches about 10%, ranging from 930 rot/min to 1750-1800 rot/min (Fig. 4d)
- The hourly fuel consumption increases from 0.63 l/h to 1.4 l/h in cases of major pressure loss (the nozzle with a diameter of 6 mm), with an engine load of 3%; when the automobile's speed is 0; the hourly fuel consumption increases by the same growth rate (doubling its value from 1.08 l/h to approximately 2.1 l/h at a speed of 36 km/h and a load of 10% - as seen in Fig. 5d)

During these experiments, we were able to observe changes in the dynamic performances of the automobile as the pressure losses in the intake manifold amplified. Small engine loads lead to significantly increased engine rotations and fuel consumption. Despite the increases in engine load and in the automobile's speed, the engine's rotation speed and the fuel consumption (influenced by pressure loss) recorded a smaller growth.

Furthermore, the next conclusion that can be drawn from these experiments is referring to the onboard diagnosis of sensors that are not working properly and the subsequent alerting of the driver through the lighting of a MIL warning lamp. The partial malfunctioning of a sensor, through the interruption of one or more circuits, leads to the immediate switching on of the MIL lamp located on board, as seen in figure 6a and 7a. The malfunctioning of the oxygen sensor is not immediately followed by the lighting of the MIL lamp because the on-board computer takes a series of proofing tests on the sensor that exceeds the 15-25 seconds time interval (as seen in Table no. 2, SO1-SO12P3 probes).

When the mass circuit is common to multiple sensors, its malfunctioning can no longer be recognized by the on-board computer and not even by the diagnosing device (as seen in Table no. 2, TPS1P1, TPS1P2, MAP1 and SO1).
During the study, changes of the car's dynamic performance have been revealed, following the amplification of pressure losses in the intake manifold, with a considerable increase of fuel consumption.

The diagnostic process also comprised experimental studies of malfunctions which are not indicated on board (such as the interruption of circuits for the lambda sensor) or by the diagnostic device (for example, which circuits are defective / interrupted or how great the pressure loss in the intake manifold is).

B I B L I O G R A P H Y

[1] *M. Sachenbacher,* A Prototype for Model-based On-board Diagnosis of Automotive Systems, Technische Universität München, Germany, 2003

[2] *Tânjală, Vasile*, Reliability, Submitted Paper no. 1, University POLITEHNICA of Bucharest, 2009

[3] *Tânjală, Vasile*, The Maintenance of Equipments, Submitted Paper no. 3, University POLITEHNICA of Bucharest, 2010

[4] *Birnbaum*, Ralph, *Truglia*, Jerry. Getting to Know OBD II, New York, 2009

[5] *I.Copae*, Dinamica automobilelor. Teorie şi experimentări (The Dynamics of Automobiles. Theory and Experimental Tests), Editura Academiei Tehnice Militare (Technical Military Academy Publishing House), Bucharest, 2003 (in Romanian)

[6] *Daewoo Cielo Euro 3 – Service Operations Handbook*

[7] *Statistic Toolbox for Use with Matlab*, http://mathworks.com, accessed in January 2011

[8] On-Board Diagnostics for Light and Medium Duty Vehicles Standards Manual - 2010 Edition, SAE (Society for Automotive Engineers) International, December 2009