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SIMULATION OF MISFIRE IN VEHICLES WITH SI ENGINE

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Abstract

The engine failure consisting in a lack of combustion in particular cylinders, commonly called as an engine misfire, is defined in the Directive 98/69 of the European Parliament which states that „engine misfire means lack of combustion in the cylinder of a spark-ignition engine caused by a lack of an ignition spark, poor mixture, too low compression ratio value, or any other reason". The engine misfire always leads to an increase in the engine exhaust system emission and it can result in an irreversible damage of the catalytic converter resulting from exceeding its admissible operating temperature. The vehicle with the damaged catalytic converter becomes an origin of an intensive emission from the engine exhaust system. Therefore the primary requirement of all OBD standards is an obligation to provide constant monitoring of the engine misfire events for the spark-ignition engines (SI) and to identify the cylinder number of the engine in which a lack of combustion occurs. OBD system is assembly diagnostic test, analytical and decision procedures realization in actual time for the purpose improvement emission efficiency and efficiency of components responsible for passive and active safety of vehicles. OBD system is integral components of vehicles with connecting with control module of engine (sensor, controller, actuator devices) One of the basic problem connected with OBD technology is test of on board diagnostic efficiency in different application. Self-diagnostic is to minimize the volume of substances generated by the combustion engines polluting the natural environment. Self-diagnostic is the basis for creating the best conditions for the most effective operation of the engine. Those paper include same results of testing and possibilities monitoring of catalytically converter in SI engine and simulating of signal from oxygen sensor. There are results of simulation of misfire in these engine.

1. Introduction

The engine failure consisting in a lack of combustion in particular cylinders, commonly called as an engine misfire, is defined in the Directive 98/69 of the European Parliament which states that „engine misfire means lack of combustion in the cylinder of a spark-ignition engine caused by a lack of an ignition spark, poor mixture, too low compression ratio value, or any other reason". The engine misfire always leads to an increase in the engine exhaust system emission and it can result in an irreversible damage of the catalytic converter resulting from exceeding its admissible operating temperature. The vehicle with the damaged catalytic converter becomes an origin of an intensive emission from the engine exhaust system. Therefore the primary requirement of all OBD standards is an obligation to provide constant monitoring of the engine misfire events for the spark-ignition engines (SI) and to identify the cylinder number of the engine in which a lack of combustion occurs.

From a perspective of years one can state that the first OBD systems made performing the diagnostic of the injection-ignition system possible, however, they did not take into consideration any driving and emission characteristics. For example, the vehicle with the worn catalytic converter causing an evidently unacceptable increase in emission was considered as being in working order unless the OBD system had detected any failures of the checked elements.

Similarly, a car in which the misfiring effect occurred and caused an increase in the hydrocarbons emission was also considered as one in working order. The first diagnostic systems OBD I were characterized by its certain variety and somehow „private specification". The individual manufacturers used their own electric and logic standards for data transmission from the system and considered any information concerning the error codes and the engine condition as some manufacturing knowledge accessible for the limited number of consumers only. Generally speaking, the diagnostic procedure preceding the OBD II system made the vehicle's service and repairs easier, however, it did not tend to any significant reduction in the emission from the motor transport.

2. Main rules of OBD II/EOBD system

The OBD II standard accepted in the USA is based on the admissible limits for the emissions examined in the FTP 75 test (FTP-Federal Test Procedure*)*, however, its European equivalent, i.e. the EOBD standard, is based on the limits of emissions checked according to the ECE R83 test. In accordance with the Directive 98/69/EC, since January 2000 for the spark-ignition engine vehicles of the M1 category (passenger cars, number of seats up to 9) the OBD requirements have been used for new types (new certifications), and since January 2001 they have been applied to all newly registered vehicles. In accordance to the ECE R83.05 Regulations, since March 29, 2001 the EOBD system must be used in all European countries [1-6]. The availability of the diagnostic connection and the transmission data protocol have to be in conformity with the SAE settlements (Fig. 1 and Fig. 2).

The performed investigations allowed for analysing the extent of the implementation of the OBD system to the cars available on the market in Poland, and to the cars made by American producers as well. On the basis of the performed analyses the graph showing the percentage of using the individual data transmission systems for the individual kinds of cars was plotted. The extent of the implementation of the OBD system to the vehicles differs depending on the engine kind (type) so the vehicles are divided into two groups, one group equipped with the spark ignition engines and the other one with the compression-ignition engines (Fig. 3).

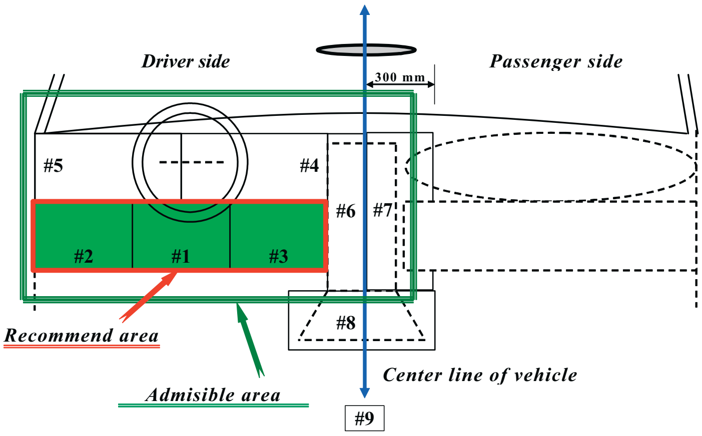

Fig. 1. Possibilities of an OBD connector localization according to SAE regulations

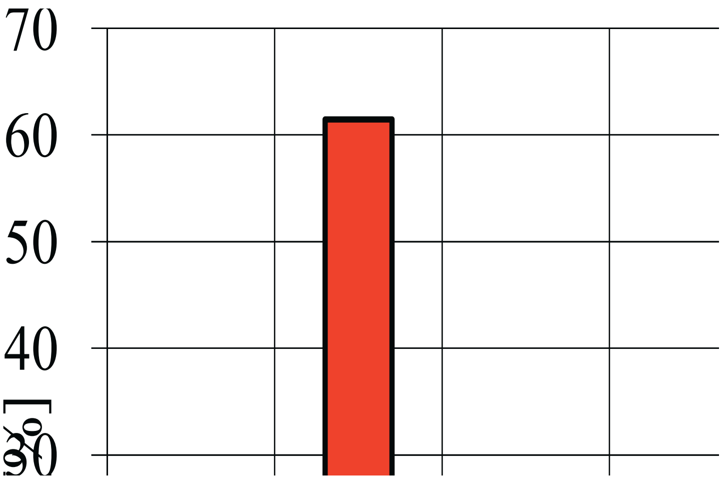

Fig. 2. Percentage share of OBD connectors in cars on the polish market (amount of cars - 100)

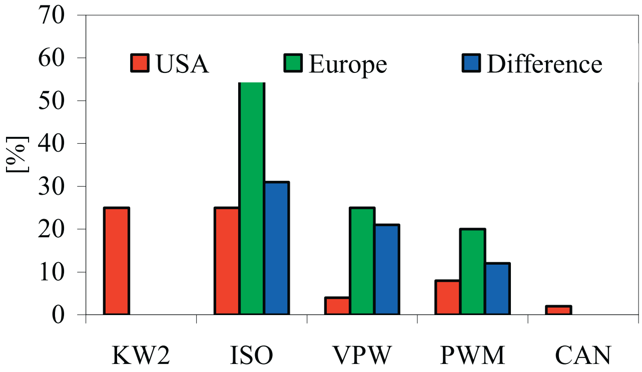

Fig. 3. The percentage share of protocol data transmission of the USA and European market cars and differences between them (the amount of cars - 130)

The OBD II system was introduced (according to the EURO III Standard) as an additional equipment for the compression-ignition engines used in the passenger cars of the M1 category and trucks of the class I N1 category (light car vehicles, vehicles with complete vehicle curb weight up to 3500 kg), and from January 2005 - also for trucks of the class II and III N1 category. According to this standard regulations the useful life periods have been extended to the mileage of 100 000 km for all components which significantly affect the exhaust emission (for all emission-related elements). In accordance with the EOBD standard, the emission threshold limits for the harmful exhaust gas components concerning the detection of malfunctions in a system affecting their emission (in an emission-related system) are presented in Fig. 4.

The future requirements for all vehicles are as follows:

- a complex electronic control of all devices limiting the exhaust emission,
- a separate diagnosis provided for the front catalytic converter or in combination with the other one placed downstream the exhaust gas flow,
- recording the vehicle operation time after the failure event occurrence,
- lack of monitoring the engine misfire if for its determination the influence of other actions is also taken into account,
- normalization of error codes, data transfers, diagnostic devices and connections according to the ISO standards (International Organisation for Standardization),
- providing the service by the makers of vehicles with all necessary information with exception the intellectual property legally protected,
- activity of the OBD system up to the specified vehicle mileage,
- indicating the failure of the checked components.

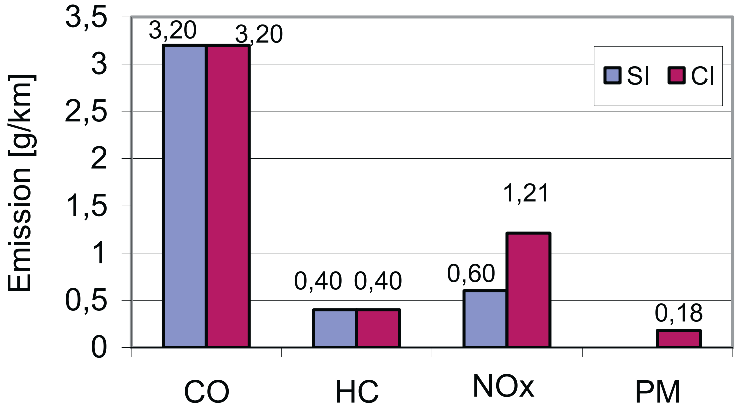

Fig. 4. Emission thresholds in the EOBD legislation for passenger cars with SI and CI engines [1–6]

3. Tested object

The purpose of the examinations was to develop and to check under the laboratory conditions the operation of devices simulating the failure of selected engine components covered by the OBD II system monitoring. The obtained results are to be applied for improving their design and implemented to the laboratory procedures. The scope of the examinations assumed performing the determination of the influence of the simulated failures on the emission of the limited gas pollutions, fuel consumption, and the driving performance of the tested vehicle. The tests were performed for the following vehicles: Fiat Panda brand new and Opel Astra. Fiat Panda was equipped by its maker with the OBD II system, whereas Opel Astra was subject to some complementary examinations.

4. Running of investigation

The measurements of the total vehicle friction loss on the road were carried out by a cast down test method according to the Regulation no.83 UN/ECE (Supplement 3 to Annex 4).

Tab. 1 presents total corrected force and vehicle on a road friction loss values, whereas the coefficients of the friction loss characteristics are presented in Tab. 2.

Tab. 1. The force and power of a total aerodynamic resistance for a Fiat Panda car

Speed [km/h]	Force [N]	Power [kW]
120	720	24.0
110	637	19.4
100	559	15.5
90	484	12.2
80	430	9.6
70	368	7.2
60	321	5.4
50	282	3.9
40	243	2.7
30	222	1.8
20	181	1.0

The harmful components emissions from the exhaust system after a cold start at normal ambient temperature of (20-30ºC) and the fuel consumption were measured in the Type I test (Regulation no.83 UN/ECE, series 5 of Supplements) for different percentages of „misfire" events. The „misfire" defect was generating by the AMX 700, version II, device.

Tab. 2. The curve coefficient of a total aerodynamic resistance on the road for a Fiat Panda car

F_0 [N]	162.9
F_1 [Ns/m]	2.40
F_2 [Ns^2/m^2]	0.4278

The results of the pollutant emissions and fuel consumptions measurements are shown in figures 5-7.

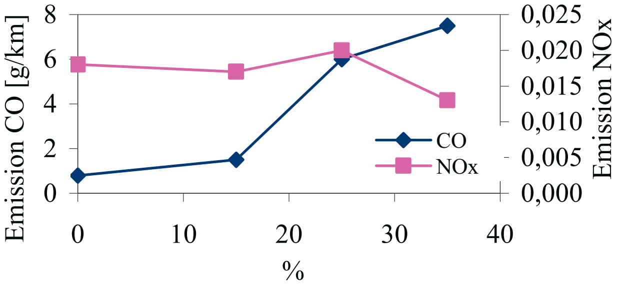

Fig. 5. The modification of the CO and NOx emission in function of positioning misfire in the test type I Regulations 83 EKG UNO, the 05 series correction - the weighted average (the test after a cold start)

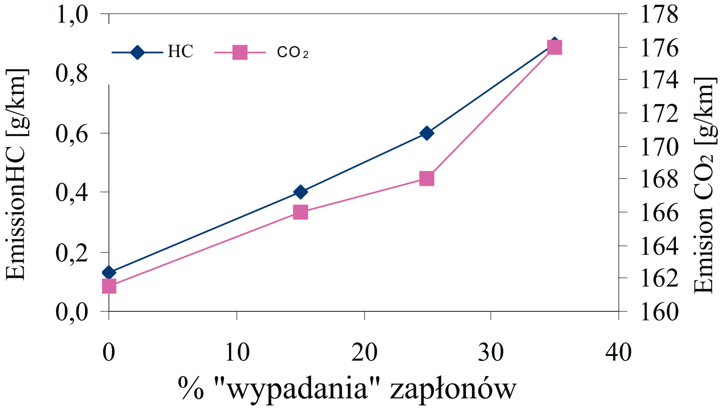

Fig. 6. The modification of the HC and CO_2 emission in function of positioning misfire in the test type I Regulations 83 EKG UNO, the 05 series correction - the weighted average (the test after a cold start)

The „misfire" defect was set on the cylinder no. 2 at synchronization with the cylinder no. 1. For every one per cent of the „misfire" events it was checked whether any expectation error had appeared or MIL lamp (Malfunction Indicator Light) had lighted. Three driving cycles were realised at the percentage of 15% of „misfire" events and ten cycles at 25%. At the percentage of 35% of „misfire" events and after realisation of three driving cycles the expectation error occurred, however, the MIL lamp did not light. Next the driving test was performed consisting in driving under the urban traffic conditions. The MIL lamp started lighting after three driving cycles and travelling the distance of 70 km (error nos. P0300 and P0302 - multiple „misfire" events).

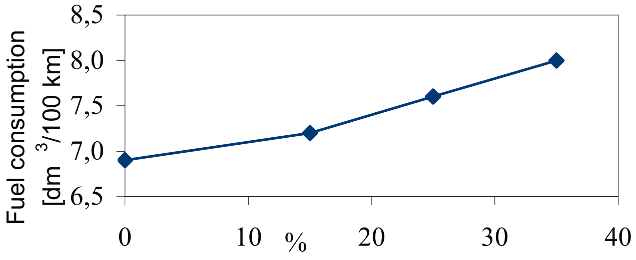

Fig. 7. The modification of a fuel consumption in function of positioning misfire in the test type I Regulations 83 EKG UNO, the 05 series correction – the weighted average (the test after a cold start)

During the exhaust emission measurements, after cold starting at the ambient temperature of (-7ºC), the „misfire" event was set on the cylinder no. 2 at synchronization with the cylinder no. 1. After each test it was checked whether the OBD system had detected the „misfire" events. The errors P0300 and P0302 occurred only at the percentage of the „misfire" events of 35%, however, the MIL lamp did not light.

The measuring results are presented in Fig. 8-10.

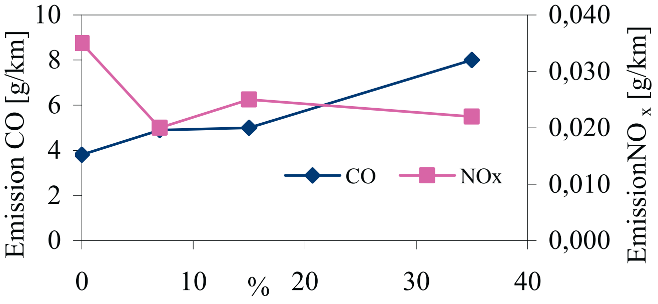

Fig. 8. The modification of the CO and NO$_x$ emission in function of positioning misfire in the test type I Regulations 83 EKG UNO, the 05 series correction - the weighted average (the test after a cold start in the temperature -7ºC)

The traction characteristics of the vehicle was also examined by measuring the changes in the net output at wheels for different percentages of the „misfire" events. The measurements were taken for the fifth gear at driving velocities ranging from 60 to 150 km/h.

Fig. 11 shows the results of the decrease in the net output at wheels measurements taken for different percentages of „misfire" events in relation to the output power measured with no „misfire" events recorded.

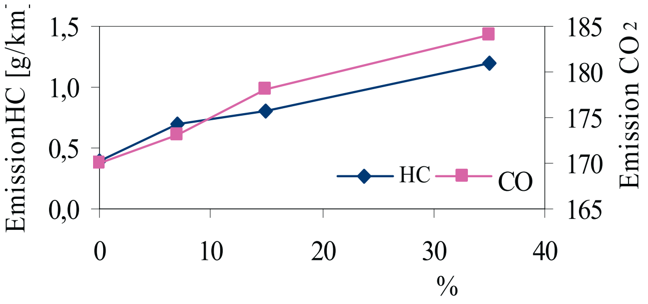

Fig. 9. The modification of the HC and CO$_2$ emission in function of positioning misfire in the test type I Regulations 83 EKG UNO, the 05 series correction - the weighted average (the test after a cold start in the temperature -7ºC)

As the percentage of „misfire" events increases the value of the net output decrease at wheels of the tested vehicle increases as well. At small values of the engine crankshaft speed the effect of the changes in the „misfire" events percentage was smaller in comparison with the one noted at the rated engine output speed.

To perform the comparative tests of the exhaust emissions from the exhaust system of a car equipped with a spark-ignition system, SI, with a multi-points fuel injection, the AMX 700 device was installed. That device was used for forcing an incorrect operation of the ignition system by preventing the conditions essential for forming a spark between the spark plug electrodes. The „misfire" event failure was simulated on the cylinder no.2 of the engine.

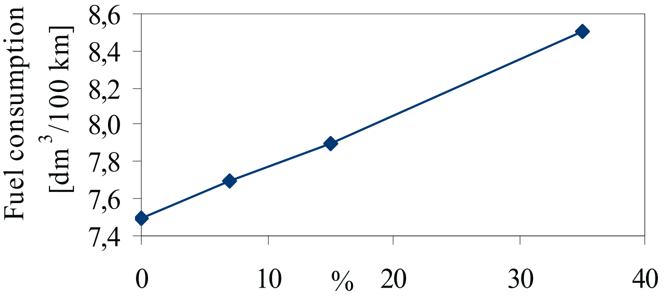

Fig. 10. The modification of the fuel consumption in function of positioning misfire in the test type I Regulations 83 EKG UNO, the 05 series correction - the weighted average (the test after a cold start in the temperature -7ºC)

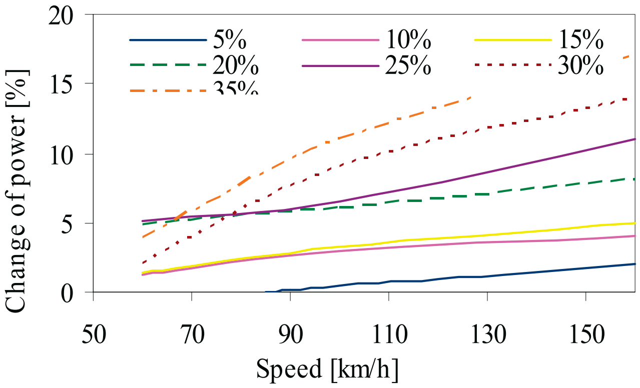

Fig. 11. The relative modification of the net power on wheels during different settings of a misfire in relation to measurement value without a misfire

During the examinations the following actions were carried out, namely:

- the measurements of the concentrations of the harmful exhaust emission from the engine exhaust system were taken according to the provisions of the Regulation no.83 UN/ECE, series 04 of Amendments, at the „misfire" events percentage for one of the cylinders increasing from 0 to 30% (Tab. 3),
- the measurements of the concentrations of the harmful exhaust gas components in the engine exhaust system were carried out with the use of the diagnostics analyser at a percentage of the „misfire" events for one of the cylinder increasing from 0 to 40%,
- the characteristics of a voltage signal from the lambda probe at the idle running speed and its increased value as well, without „misfiring" and for the percentage of the „misfire" events of 35% for one of the cylinders.

In order to evaluate the changes in the concentrations of the harmful exhaust gas components and composition of the air-fuel mixture against the „misfire" events percentage under the measurement conditions corresponding to the ones of technical examinations some additional tests were performed which consisted of (Tab. 4):

- the measurements of the CO, HC, CO_2 and O_2 concentrations and the mixture composition taking into account the excess air number for the engine operating point under the idle running conditions,

- the measurements of the CO, HC, CO_2 and O_2 concentrations and the mixture composition taking into account the excess air number for the engine operation under the increased idle running speed conditions (~3000 rpm).

Tab. 3. Results of the emission measurement in driving cycles

% „misfire”		0%	10%	15%	20%	30%
Emission		[g/km]	[g/km]	[g/km]	[g/km]	[g/km]
UDC	CO	5.479	7.889	7.807	7.920	15.24
	NO_x	0.126	0.251	0.295	0.193	0.463
	HC	0.301	0.711	0.772	0.847	2.525
	CO_2	252.0	261.9	275.0	271.2	251.0
EUDC	CO	0.656	0.841	0.950	2.341	1.861
	NO_x	0.059	0.065	0.091	0.113	0.076
	HC	0.045	0.075	0.095	0.253	0.233
	CO_2	150.6	148.9	156.2	153.9	159.8
Average	CO	2.422	3.436	3.459	4.394	6.776
	NO_x	0.084	0.134	0.166	0.142	0.218
	HC	0.139	0.309	0.343	0.471	1.075
	CO_2	187.7	190.5	199.7	197.1	193.3
Fuel consumption [dm^3/100km]						
UDC		11.0	11.6	12.2	12.0	11.9
EUDC		6.4	6.3	6.6	6.7	6.9
Average		8.1	8.3	8.7	8.6	8.7

The performed investigations show that there are some significant differences between the characteristics of the concentrations of the harmful exhaust gas components obtained for the engine operating without and with „misfire” events. In the first case the concentrations were adjusted in a variable way from the values corresponding to n = 3000 rpm to the ones of the idle running. The stabilization state was obtained after 30 seconds. In the second case a decrease of concentrations to the very small ones was recorded after 30 seconds, and after 80 seconds a significant increase in their values was noted. The stabilization was obtained after 150 s, however, some oscillations near the average value were still occurring, what was likely caused by a fan switching on in the cooling system.

At the speed value of 3000 rpm an increase in the preset percentage of the „misfire” events resulted in:

- an increase in the CO and HC concentrations,
- a decrease in the CO_2 concentration,
- a decrease in the excess air number,

whereas after the stabilization of indications at speed corresponding the idle running conditions it resulted in:

- an increase in the CO and HC concentrations,
- a decrease in the CO_2 concentration,
- an increase in the excess air number.

Tab. 4. The measurements results of the CO, HC, CO_2 concentration and the air factor in different settings of the 35% misfire in a different configuration of the AMX 790 device

Palace of „misfire”	n = 3000 obr/min				Idle			
	CO	HC	CO_2	λ	CO	HC	CO_2	λ
clinder 2	0,63	439	14.7	0.972	0.16	273	11.3	1.277
cylinder 3	0,12	68	15.1	1.001	0.34	199	11.2	1.294
cylinder 2 & 3	0,68	573	14.8	0.967	0.43	200	9.2	1.536
cylinder 1	0.14	59	15.2	0.999	0.38	298	11.5	1.259
cylinder 4	0.70	574	14.8	0.965	0.24	476	11.4	1.263
Cylinder 1 & 4	0.76	615	14.8	0.968	0.47	189	8.5	1.626

During the performed measurements it was observed that the CO, HC and CO_2 concentrations and the mixture composition depend not only on the percentage of the „misfire” events but also on settings on the AMX 790 device for a cylinder, which the synchronization comes from and a cylinder/cylinders in which the „misfire” events occur.

Some tests verifying the correctness of operation of the AMX 790 device were carried out in the aspect of a possibility of its software improvement. The operation of the Version II of AMX 790 device was subject to an evaluation. Special emphasis was put on checking whether there was a conformity of a programmed percentage of ignitions in which the „misfire” events were expected with a real percentage recorded under the engine operating conditions.

For comparing the programmed and real percentages of „misfired” ignitions a certain research method was developed. That method allowed for:

- evaluation of the engine operation with and without forcing the „misfire” events,
- developing the method for measuring the real percentage of „misfired” ignitions,
- checking whether the defects detected for the version I of the device can be also detected for the version II,
- measuring the real percentage of „misfired” ignitions against the engine speed.

The device’s task is to force the „misfired” ignitions in the spark-ignition engines. It can be realized by changing the voltage characteristics in a low voltage circuit of the ignition installation by shorting it to frame or to the battery positive electrode. It prevents from generating the pulse in a high voltage circuit of the ignition unit which is necessary to force a spark between the ignition plug electrodes.

The device is expected to be provided in cars for which the ignition installation is equipped with more than one high voltage coils. The device's design calls for taking a synchronizing signal from one of the low voltage circuits and calculating on its base a time in which the individual low voltage circuits interfere in the circuits of other high voltage coils.

The device's software provided a possibility for determining what a percentage of ignitions was to be „cut out", and in what cycle, and on which cylinder it was to be done. Programming any sequence of the „misfired" ignitions consisting of (up to) 1000 items was possible.

During all performed tests the device was synchronized by a signal from the ignition coil for the cylinders 1-4 forcing the „misfired" ignitions for the cylinders 2 and 3 at one programmed speed range (600-4000 rpm). The subject of tests was a passenger car of Opel make. Two testing methods were used. In the first part a method of checking the real percentage of „misfired" ignitions based on a signal from the lambda probe was used. In the adaptive engine operation managing systems the mixture composition is monitored by a lambda probe monitored (installed) in the engine exhaust system. The presence in the exhaust system the exhaust gases coming from a combustion of a very rich mixture, thus containing insignificant amounts of oxygen, forces the generation of a voltage signal of 1 V, whereas, in case of exhaust gases from the very poor mixture combustion, thus containing significant amounts of oxygen - a voltage signal of 0 V is generated.

The method assumptions are as follows:

- the misfired ignition results in a lack of combustion in a cylinder; the unburnt mixture with a high oxygen content flows into the exhaust manifold; a high amount of oxygen causes a momentary drop in the lambda probe voltage,
- a signal from the lambda probe can be a basis for determining the number of engine operating cycles in which the „misfired" ignitions occurred,
- a proper operation of the AMX 790 device is confirmed if a voltage signal frequency from the lambda probe corresponds to the its programmed frequency of the „misfired" ignitions,
- the „misfired" ignitions are forced by the device operation.

The used method shows that the engine „misfire" results in the irregularity of the engine operation which is accompanied by a characteristic noise. The evaluation of the engine operation consisted in watching a control diode on the AMX device casing, which was (lighted) on while the device was forcing the „misfired" ignitions, and observing whether the mentioned disturbances (had) occurred. Such evaluation was possible at low engine speed for idle running. It was found out that usually after the diode had lighted some irregularity of the engine operation and the characteristic noise accompanying the „misfired" ignitions occurred. However, there were some cases when the engine was running with no disturbances even after the diode had lighted. It can be supposed that not in every case a real engine „misfire" occurs and a certain nonconformity of the programmed percentages of the „misfired" ignitions with the real one can appear. It was also found that some short brakes in the diode lighting had been occurred from time to time suggesting that during those brakes the „misfired" ignitions had not been realised. During the tests eight lambda probe voltage characteristics were recorded for the unloaded engine running at the following engine speeds: idle running, 2000, 3000, 3500 rpm at different settings of the „misfired" ignitions frequency. An increase in the „misfired" ignitions frequency of the AMX 790 device caused an increase in the frequency of the lambda probe signal changes. However, in case of all settings there was no conformity of the frequency of the lambda probe signal changes with the programmed „misfired" ignitions frequency.

If a frequency of the „misfired" ignitions is lower than a frequency of changes in the mixture composition adjusted by an engine controller it is difficult to distinguish a drop in the lambda probe voltage resulting from a typical mixture composition regulation process from the one caused by the engine „misfired" ignitions. The works [?] suggested that under some engine operating conditions an occurrence of certain nonconformities of the percentage of „misfired" ignitions programmed in the AMX 790 device with the real one would be possible. The performed tests verify such a possibility. The evaluation of the correctness of operation of the device in respect of a conformity of the programmed percentage of the „misfired" ignitions with the real one on the basis of an analysis of the lambda probe voltage characteristics gave a positive result at the idle running speed. However, at speeds of 2000, 3000 and 3500 rpm a frequency of changes of the lambda probe voltage is different by 33 % from the „misfired" ignitions frequency programmed in the device. The difference is approximately constant, independent on the engine crankshaft speed and the device's settings. The obtained results of tests do not confirm the correct operation of the device, however, they cannot be regarded as an unambiguous evidence of a wrong measurement of the „misfired" ignitions number. Such situation made a modification of the applied research programme necessary. A new research programme consisted in measuring the voltage characteristics in the ignition unit on the primary winding of an ignition plug. The number of the „cut out" ignitions and sequences of their occurrence were subject to evaluation. The lambda probe voltage was also measured.

The tests showed, in most cases, the conformity of „cutting out" ignitions characteristics at the idling running speed with the characteristics programmed in the AMX 790 device. However, some cases were noted in which the pulses for the ignition „cutting out" were omitted or mistaken. Despite the detected errors the frequencies of the real „cutting out" pulses were slightly different than the programmed ones.

For the speed of 2000 rpm it was found out that:

- the „cutting out "was recorded for two subsequent pulses though the „misfired" ignition was programmed for one of cylinders,
- after programming an ignition „cutting out" on two cylinders the preceding pulse was deformed,
- irrespective of whether the misfire was programmed for one or two cylinders the frequency of pulse cutting out was different than the programmed one,
- there were random disturbances in the device functioning which lasted for several or a dozen or so cycles of the engine running.

5. Summary

The operation of the AMX 790 device consists in modifying the voltage characteristics in a low voltage circuit of the ignition plug. The investigations showed that the voltage is induced in the secondary circuit. A connection between the voltage „cutting out" in the primary circuit and the lambda probe voltage characteristics allows to state that a decrease in voltage acts on the engine operation. This action confirms the expectations. Some additional engine examinations should be performed in order to confirm unambiguously that despite of the voltage drop in the primary circuit there is a spark-over in an ignition plug, and its reduced energy lowers the combustion rate. This fact intensifies irregularities in the engine operation and the HC emission.

There is no conformity of the programmed percentage of the „misfired" ignitions with the real one. Moreover, it was found that at the engine speed of 2000 rpm an increase in the percentage of the „cut out" ignitions programmed in the AMX 790 device results in, neglecting the pulses „losing", an increase in the real percentage of their „cutting out".

At the engine speed of 2000 rpm the measuring results obtained on the basis of the second method confirm the results obtained by the first method (based on the records of the lambda probe voltage characteristics). It can be supposed that the results will be also confirmed for the other values of the engine crankshaft speed.

The performed tests show that at the engine speeds higher than the idle running speed there is some nonconformity of the percentage of „misfired" ignitions programmed in the device with the real one observed during the engine running.

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Acronyms

CI	Compression Ignition,
CO	carbon monoxide,
CO_2	Carbon dioxide,
ECE	Economic Commission for Europe,
EOBD	European On-Board Diagnostic,
EUDC	Extra Urban Driving Cycle,
FTP	Federal Test Procedure,
HC	Hydrocarbons,
LDV	Light Duty Vehicle,
MIL	Malfunction Indicator Light,
NO_x	Nitrogen oxides,
OBD I	On-Board Diagnostics I,
OBD II	On-Board Diagnostics II,
OBD III	On-Board Diagnostics III,
OBD	On-Board Diagnostic,
PC	Passenger Car,
SAE	Society of Automotive Engineers,
SI	Spark Ignition,
UDC	Urban Driving Cycle.