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The impact of parameter modifications in the Diesel engine power system on the emissions of harmful compounds

The article presents the results of emission tests and vehicle operation indicators fueled with diesel oil. The tests were carried out for a passenger vehicle equipped with a diesel engine meeting Euro 3 emissions standard, moving in urban traffic. The measurements were carried out using modern PEMS (Portable Emission Measurement System) enabling the emission of gaseous components from exhaust systems of the tested object. On the basis of the conducted tests, the load characteristics were determined using the torque values obtained along with the engine speeds. The measurement route included two cycles: urban driving and fast acceleration. The aim of the study was to assess the impact of modifications to the control maps on CO, CO_2, PM and NO_x exhaust gas emissions under real operating conditions.

Key words: *IC engine, chip-tuning, CI, PEMS*

1. Introduction

The operation of the drive units in the currently manufactured vehicles corresponds to ECU electronic controllers. (ECU – Engine Control Unit). In comparison to the mechanical solutions, these controllers take into account, among others, the degree of wear of power system components. Thanks to this, it is possible to apply some necessary compensations that allow a proper engine operation. Besides controlling other parameters affecting the operation of the drive unit, the electronic control introduces the possibility of changing the control algorithm. This procedure is known as chip-tuning. The user's desired effect is to increase the power and torque generated by the engine without the need for mechanical changes. The side effect of the change in the control algorithm changes the engine's operating conditions that causes a critical increase in the emissions of harmful compounds [1, 2].

2. Parameter modifications in the engine power system

2.1. Test unit

The unit under test was an Audi A4 passenger car manufactured in 2001. It is equipped with a self-ignition engine with AWX pump injectors. The engine displacement is 1896 cm^3. The maximum torque declared by the manufacturer is 285 Nm and occurs within the speed range 1750-2500 rpm, while the maximum generated power is 96 kW at 4000 rpm.

2.2. Measuring apparatus

Figure 2 presents a mobile Axion R/S+ device, manufactured by Global MRV, which was used to carry out the measurements. It is intended for research in the real traffic conditions and classified in the PEMS (Portable Emissions Measurement Systems) group. The device allows testing both CI and SI engines. To measure the mass flowing through the air motor, an external Semtech EFM flowmeter was used as shown in Fig. 3.The analyzer enables synchronization with the GPS positioning system as well as communication with the vehicle OBD. Based on the obtained road emissions results, it is possible to determine the fuel consumption using the carbon balance method.

Fig. 1. The car used for tests

Fig. 2. View of the Axion R/S+ mobile device

Fig. 3. Semtech EFM flowmeter

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2.3. The test route in Poznań, Poland

The measurements of exhaust emissions were carried out during rapid acceleration of the car from 0 km/h to 90 km/h along the test route in the urban traffic conditions shown in Fig. 4. The vehicle traveled the same route three times. Once for every set of control maps. The vehicle was heated to a coolant temperature of 90°C at the start of the measurements. The measurements were made on the same section of the route at a constant external temperature.

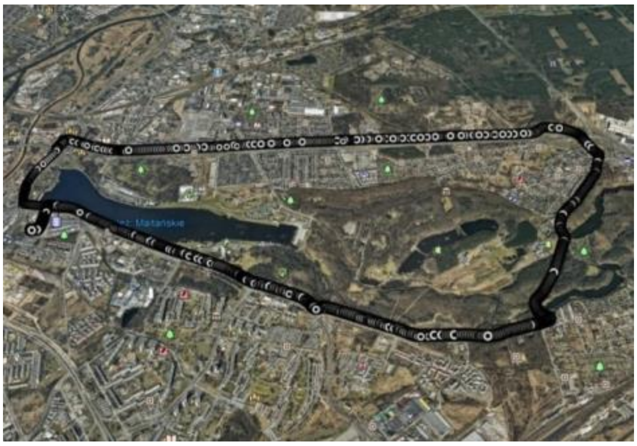

Fig. 4. Test route in Poznań

2.4. Parameter modifications in the engine power system

Parameter modifications were carried out within the speed ranges at which the drive unit reaches the highest power and the highest torque. Within the range of maximum torque, the fuel dose increased by 23%, while at the speed at which the engine reaches the highest power, the fuel dose increased by 15%. Whereas the two modified sets of control maps have the same injection maps to define the amount of injected fuel, they have different recharge pressures. The changes are shown in Fig. 5 for the first change of power supply parameters and Fig. 6 for the second change of power supply parameters [5].

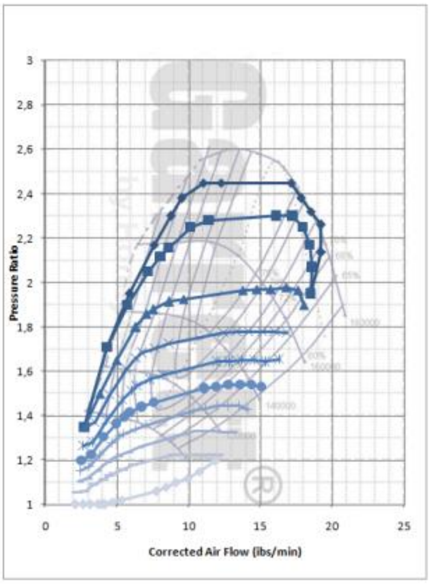

Fig. 5. The course of the boost pressure – serial 1

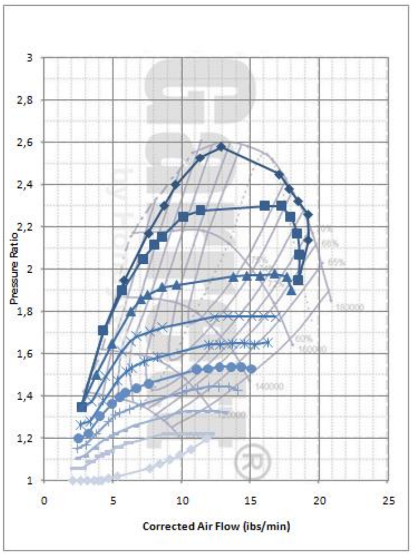

Fig. 6. The course of the boost pressure – serial 2

3. Research results with analysis

3.1. Power and torque measurements

Measurements of power and torque were made with the Dynomet portable road test bench, characterized by a measurement error of 2%. The measuring device was mounted next to the wheel of the vehicle as shown in Fig. 7. Before performing the measurements, the dynamometer was configured with the following parameters:

- ambient temperature,
- atmospheric pressure,
- the dynamic radius of the wheel,
- mass of the vehicle with passengers.

The measurement results are in Table 1.

Fig. 7. Assembly of the road test bench

Table 1. Results of power and torque measurement

Set of maps	Ne [kW]	n [rpm] Ne max	Mo [Nm]	n [rpm] Mo max
The original	104.4	4040	294	2250
Mod. 1	115.5	3772	338.5	2385
Mod. 2	113.3	3812	337.4	2271

3.2. Measurement of emissions in the city traffic

Figure 8 shows the course of change of the fuel dose injected for one cycle of work as a function of engine speed. The maximum fuel dose stored in the original torque limiter map determines the maximum amount of fuel that can be injected into the combustion chamber. The area above the straight line consists of points that refer to engine work with modified maps. The closed field encompasses an area of change in the boost pressure and shows the engine work in which the boost pressure was modified. The chart shows the dependence of the fuel dose on the rotational speed, since the value of the boost pressure generated by the turbocharger depends on the engine speed and the fuel dose. During the measurements, the engine worked mainly within the same range of rotational speed and amount of fuel dose. This means that the engine worked mainly in unchanged areas of the engine map, and that the changes in the burned fuel result mainly from changes in the time interval of the car run. The points visible in the fields of the modified engine work determine the results obtained during the exhaust emission tests at the moment of acceleration. This issue will be described in detail in the next paragraph.

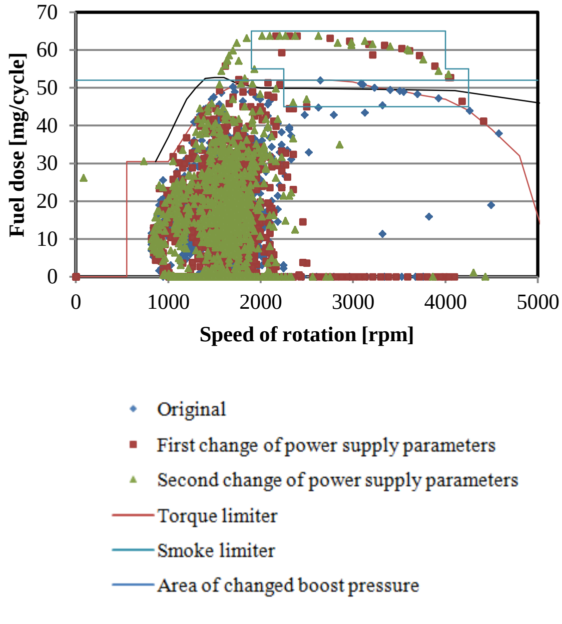

Fig. 8. Engine work points during car run

3.3. Emissions measurement during acceleration

Figure 9 shows the course of rotational speed during acceleration from 0 km/h to 90 km/h while performing emissions measurements. The figure shows how the driver changed gears while taking measurements.

During the second measurement, the change from the first to the second gear was made faster than in the case of the first and the last measurements. This means that during the second measurement the motor was more loaded until it reached the rotational speed of 2600 rpm. The first gear has a higher gear ratio than the other ones, hence the load on the drive unit is higher and the acceleration takes more time.

The emissions of the diesel engine with the AWX factory mark during acceleration from 0 km/h to 90 km/h is shown in Fig. 10. The emissions of nitrogen oxides from an engine operating with the first set of modified maps increased by 2.7%, while operating with the second set of modified maps the nitrogen oxide emissions decreased by 2.5%. In both modified sets of maps, the excess air ratio was significantly reduced, which means that blends formed in the combustion chamber were richer. On the basis of the course shown in Fig. 11, it can be concluded that together with the decrease of the excess air coefficient, the concentration of nitrogen oxides in the exhaust gas increases. The mass of the particulate matter (PM) emitted by the engine also increased in the case of the modified engine control maps. In the case of the first change of power supply parameters, at a lower boost pressure, the increase is by 88%, while in the case of the second change of power supply parameters, with a larger amount of air supplied by the turbocharger, the increase is by 16%.

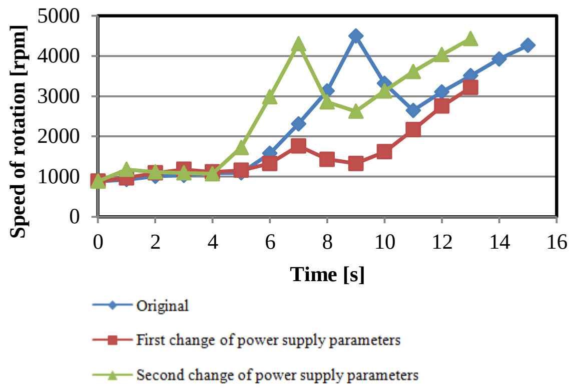

Fig. 9. Changing the rotational speed during acceleration

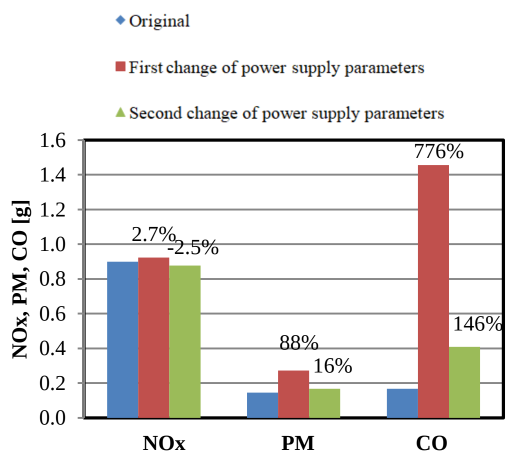

Fig. 10. Emissions of toxic compounds during acceleration

The biggest changes were observed during measurements of carbon oxides emissions. In the case of the first set of maps, the emissions increased by 776%, which is significant in comparison to the original software. When measuring the emissions from the engine working with the second change of power supply parameters, this increase also occurred, but definitely to a lesser extent than compared to the first set, which was 146%.

During the acceleration of the car with the first set of modified maps, the driver changed the first gear to the second one faster than in the case of with the original maps and the second change of power supply parameters. For this reason, in order to increase the accuracy of the test, the emissions of toxic components were measured from the rotation speed above 2600 rpm on the second transmission ratio to the end of the measurements. Measurement results show no change in the particulate matter emissions, contrary to emissions of nitrogen oxides and carbon monoxide which changed. The emissions of nitrogen oxides within this range of rotation speed increased for each set of modified control maps. It is consistent with the course shown in Fig. 11. The measurement results of the carbon dioxide emissions (Fig. 12) indicate that the highest emissions appear during engine operation with the first set of modified maps.

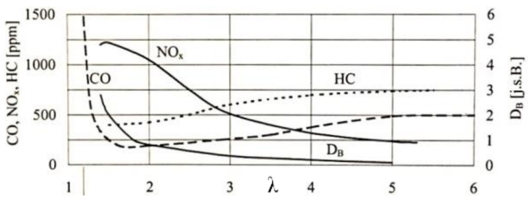

Fig. 11. Dependence of CO, HC, NO_x, D_B opacity of particulate matter on the λ excess air ratio for the Diesel engine [3, 4]

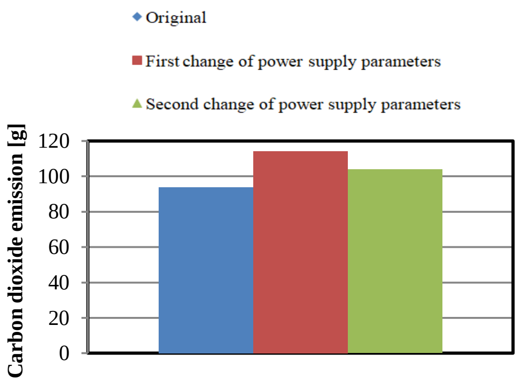

Fig. 12. Carbon dioxide emissions during the test in similar engine operating conditions

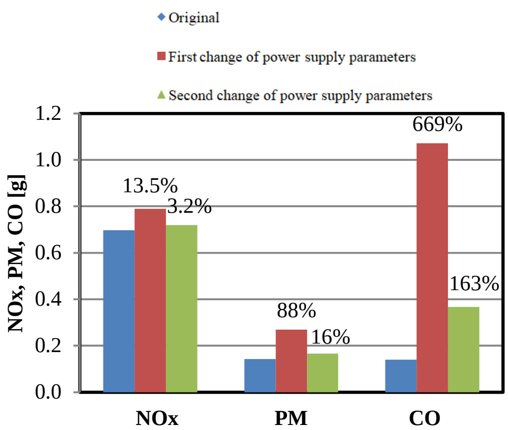

Fig. 13. Mass of toxic compounds during acceleration in similar engine operating conditions

4. Summary

The tested car was equipped with a CI engine, which it is often subjected to power boosting. Its durability is also the reason why there are so many depleted cars still in use whose worn piston-cylinder units significantly increase the emissions of harmful compounds as the outcome of burning engine oil. The wear of these parts, combined with the increased boost pressure and the increased fuel dose, leads to an increase in the indicated pressure, and thus a higher performance power. The increase of the indicated pressure facilitates the increase of the so-called "blows" in the crankcase. The desecration of the crankcase is most often directed to the intake manifold. Together with the gases that permeate from the combustion chamber into the crankcase, small quantities of engine oil permeate into the crankcase ventilation system. The increase of the indicated pressure facilitates blowing. As a result, the amount of engine oil fed to the combustion chamber along with the gases entering the crankcase is higher, which is also the reason why the emissions of harmful compounds increase, too. During the tests, emissions were measured along the route that reflects the traffic in the urban cycle and the acceleration when the engine was operating at the highest load. The measurement results in the urban cycle indicate that the car worked mainly in the unchanged areas of the control maps. By contrast, with modified maps controlling the boost pressure and the amount of injected fuel, the measurement results of emissions during rapid acceleration clearly show that such modifications increase the emissions of toxic compounds. While boosting the engine power by applying chip-tuning at a very low AFR coefficient, the carbon monoxide emissions of the tested car during the acceleration was higher by 669%. Applying a higher charge with the same amount of injected fuel increased the emissions of CO, which was higher than CO emissions from 2 cars controlled by the original set of maps. The particulate matter emissions increased by 88% and 16% respectively for the first and the second set of modified maps. These values are very high, however it has to be pointed out that in the homologation process the test car met the Euro 3 emission standard, so it is not equipped with a PM filter. The emissions of nitrogen oxides increased in the case of each modification, but higher values occurred for the first one, where the amount of supplied air was much smaller. The increase is respectively 13.5% and 3.2% for the first and the second set of modified maps. Although power and torque reached their highest values while the engine operated on the first set of modified maps, its emissions were significantly greater than the emissions from the engine operated with the original set of control maps. The engine operated with the second set of modified control maps generated approximate values of power and torque, but the emissions from the engine running with these algorithms was much smaller than from the engine running with the first set. Treatments such as chip-tuning may, despite providing similar values of power and torque, harm the environment to a different extent. While defining more and more restrictive standards for the homologation of new cars, it has to be pointed out that attractive purchase price of the older cars, their low maintenance cost and servicing, encourages their owners to apply power-boosting measures. Therefore, the concentration of toxic compounds in the exhaust gases should be carried out both before and after the applied modifications.

Nomenclature

CI	compression ignition	DI	direct injection
CNG	compressed natural gas	LPG	liquified petrolum gas

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