ESTIMATION OF CATALYTIC CONVERTER EFFICIENCY WITH THE ASSISTANCE OF NOx SENSOR IN LIGHT OF FUNCTION OF OBD SYSTEM IN VEHICLES WITH CI ENGINES

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Abstract

One of the methods to reduce emission of toxic components is continuous control over engine elements that are directly or indirectly responsible for level of emission of these components. Introduction of these requirements caused creation of the self-diagnostic definition and utilising innovation definition self-diagnostic - self-diagnostic system comparing value of signals from circuit of electronic control device with control values. If the real signal value does not comply with control value, the memory of the control devices records the error code.

This paper include basic terms and rules of function European On Board Diagnostic in light of large quantity of vehicles in Europe and in the whole world, level of pollution environment and one of method of prevention degradation environment and basic rules according to built and monitoring of catalytic converters.

The development of a catalytic converter required an analysis of selected physical parameters of the supports. This resulted from the necessity to assume given parameters of the supports applied in the tests in exhaust gas environment in the CI engines. An analysis of ionic conductors which constitute the basic solution in voltage sensors providing signals through NO_x *electrocatalysis.*

The aim of this paper is to determine the basis for the monitoring of catalytic converters in compression ignition engines by the emission level of a selected exhaust gas component as a diagnostic signal. The emission of NO_x *has been taken as the basis. This required the development of a specialized system allowing the reduction of* NO_x *and obtaining of a diagnostic signal reflecting the level of the said reduction.*

Those paper include same results of testing and possibilities monitoring of prototype catalytic converter on the test bad.

Keywords: *monitor, OBD II, EOBD, sensor, temperature, pressure, catalytic converter.*

1. Introduction

The OBD system (*On Board Diagnostic* system; known in the United States as the OBD II system and in Europe as the EOBD one) is a set of diagnostic tests and calculation and decisive procedures which are performed in a real time and are intended as a measure for evaluation of the emission efficiency and the efficiency of elements responsible for the passive and active safety of a vehicle. The OBD system is an integral part of the vehicle connected with the engine control system. Nowadays the investigation on the on board diagnostic systems in their different applications is one of the basic problems that the OBD method is concerned with. The implementation of the investigation method for the OBD system efficiency is one of the main questions of the matter in hand.

In order to satisfy such postulates the realization of the implemented diagnostic procedures during the real operation of vehicles and in the possible shortest time is necessary. Thus the evaluation of the operating efficiency OBDE (*On Board Diagnostic Efficiency*) of the OBD system is also necessary.

2. Tested station

The engine research work presented in this paper was carried out in the laboratory of the Institute of Combustion Engines and Transport at Poznań University of Technology. For the research needs an exhaust system of the tested engine was adequately adapted. The engine test stand consisted of the following elements [4]:

- 4CT90 compression-ignition engine manufactured by WSW Andoria,
- AMX-210/100 eddy-current brake with water cooling,
- reducing catalytic converter *(catalyst*) equipped with carriers of 200 cpsi density,
- HORIBA MEXA 7100 exhaust emission analyser,
- temperature sensors,
- pressure sensor.

For determining the efficiency of the applied catalyst, and NO_x probe as well, on the adapted test stand under the engine test bench conditions (fig. 1), some preliminary tests were carried out according to the obligatory ESC (*European Stationary Cycle*) test.

A special catalytic converter equipped with carriers of 200 cpsi density was built for the test needs. It consists of five blocks with dimensions of 125×50 mm. The catalyst casing enables performing the tests for a variable number of catalytic blocks and taking the measurements behind each block.

A chemical composition of the catalytic converters was developed (*selected*) in the Institute of Internal Combustion Engines at Poznań University of Technology in cooperation with the Department of Inorganic Chemistry at AGH University of Science and Technology in Kraków. The catalytic layers were produced by means of the USPD (*Ultra Spray Pyrolysis Deposition*) and sol-gel methods for CeO_2-ZrO_2/PtPd and CeO_2-ZrO_2/PtRu components [5].

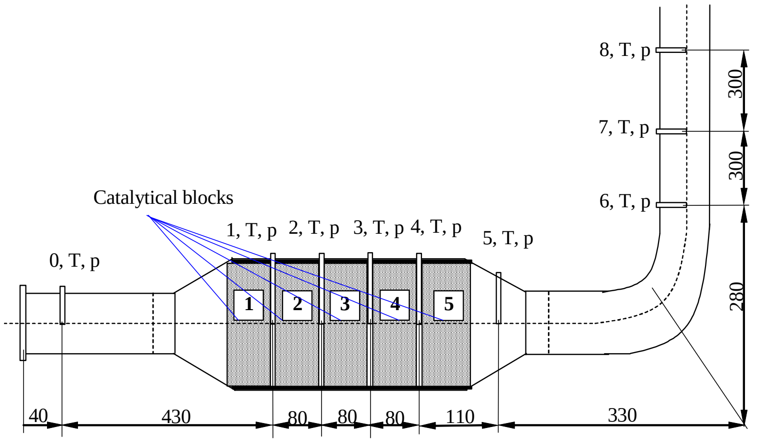

Fig. 1. Diagram of modification exhaust pipe with installed catalytically converter *in test bed and present of measurement points [3]; 0-8 – measurement points:(T) – temperature, (p) – pressure*

3. Analyses of temperatur dissolution in exhaust pipe

The temperature is a basic parameter affecting the ability of generating voltage signals by the sensors produced in the „*sensor to sensor*" technology. Owing to the design of sensors and the constructional materials used for the execution of electrodes in the individual areas, as shown in papers [3, 4, 5], it was necessary to provide an additional reheating to reach the temperatures which enable starting the oxygen pumps. Taking into consideration the operating parameters of the engine examined on the engine test bed the exhaust gas temperatures during the realization of the ESC test could reach the range in which generating the diagnostic signals by the sensors was possible. Overheating the measuring probe of a sensor caused by too high temperatures of exhaust gas while supplying a system of heaters with an external voltage can result in a degradation of electrodes. Therefore the developed laboratory system requires a manual selection of the voltage for supplying a sensor in a way eliminating a risk of exceeding the threshold voltage value for given engine operating conditions. To complete the gathered knowledge on the possibilities of delivering the supply voltage depending on the temperature in the exhaust engine system an analysis of the temperature distribution was carried out in the measuring points of the exhaust system, provided for the NO_x sensors (fig. 2 – 3) [3].

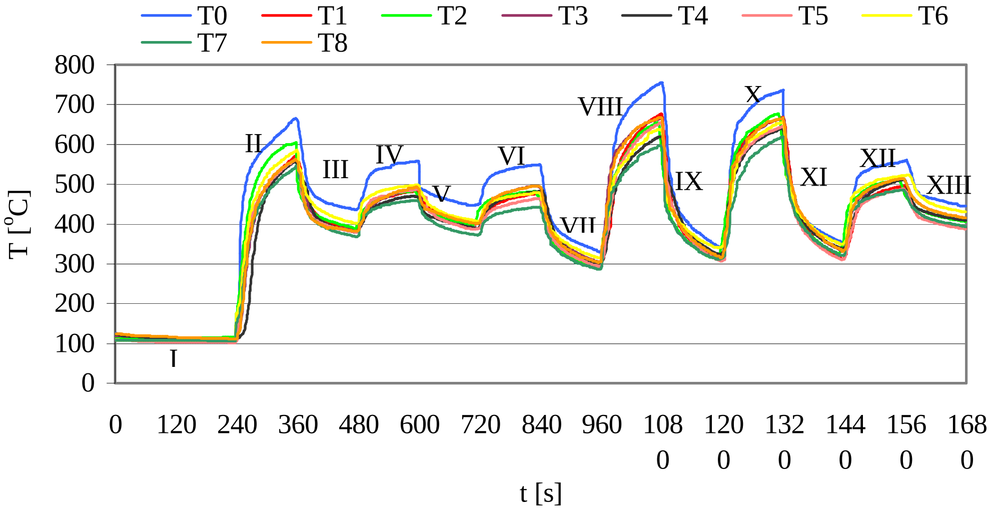

Fig. 2. Distribution of temperature in measurement point T0-T8 exhaust pipe of testing engine without catalytically converter during realization ESC test [3]

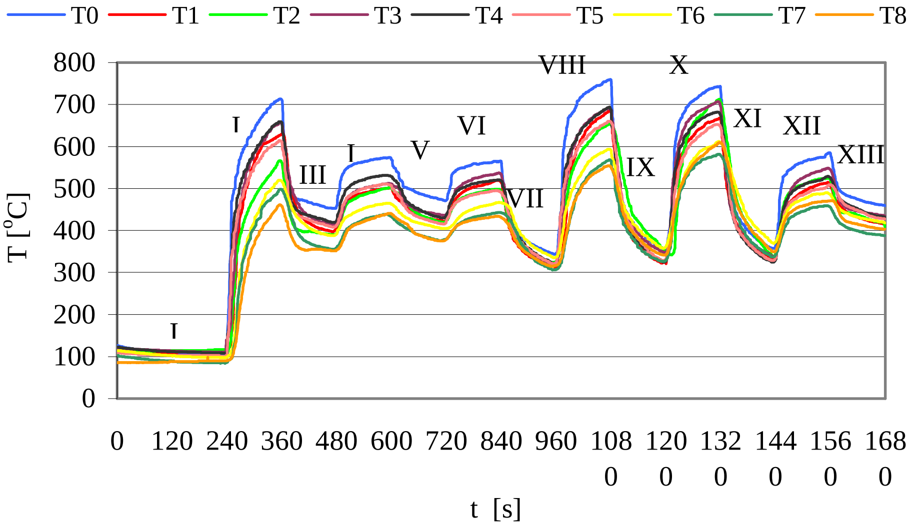

Fig. 3. Distribution of temperature in measurement point T0-T8 exhaust pipe of testing engine with 200 cpsi catalytically converter during realization ESC test [3]

The performed analysis indicates that with regard to the exhaust gas temperatures the phases II, VIII and X are most critical. It concerns both temperatures measured without and with the catalyst provided. In case of phase II the highest temperature of 710°C was reached at the T0 point of the exhaust system equipped with a catalyst with a carrier of 200 cpsi density.

In case of phases VIII and X the exhaust gas temperature were reaching the values ranging from 737°C to 759°C. These are temperatures at which the sensors, owing to their design and constructional materials for electrodes, are able to generate voltage signals without necessity of reheating. For all other test phases the highest temperatures were reached at the T0 point and the recorded temperatures were not exceeding the value of 600^{o}C.

This analysis indicates that in case of phases VIII and X, during a realization of the engine test bed examinations, the applied sensors will be most sensitive to the controlled supply voltage value. The obtained temperature distribution suggests that for these phases the sensor reactions should be fastest as the optimum sensor temperatures can be reached without necessity of reheating. However, the above applies to the sensor installed at T0.

4. Analyses of pressure dissolution in exhaust pipe

The rate of chemical reactions is a function of the reactive exhaust gas components, exhaust gas temperature, type of the applied catalyst and pressure. For reactions proceeding in a gaseous phase the concentrations and pressures are interdependent. However, the pressure can independently affect the reaction rate values, thereby the response times of the sensor in the considered system. In order to find the importance of these variables the experiments should be carry out in a way which makes possible a simultaneous change of the smallest number of parameters. It is impossible to perform such experiments in case of examination being realized under the engine test bed conditions. For this reason the importance of pressure is limited to its effect on the sensor response time with regard to the exchange of exhaust gas present in the sensor's probe.

The pressure in the exhaust system affects the intensity of the gas exchange in a sensor by affecting the pressure present in a measuring probe, as shown in papers [3, 4, 5]. When an increase in pressure in a measuring area is faster the speed of the gas exchange in the individual regions of the NO_x increases and thereby a frequency of the voltage signals should be greater.

With reference to the classic catalyst the engine exhaust system pressure results in a number of the molecules adsorbed within a catalytic layer. Regarding it to the sensor conditions a number of the collisions of oxygen molecules with the electrode *Pt* should be also higher what can directly result in the sensor response time value.

In the phase I of the test, in which the engine was operating at idling speed, the average overpressure in the exhaust system without the catalyst was of $0{,}03 \cdot 10^{-4}$ Pa (fig. 4). In case of the exhaust system equipped with the catalysts with the 200 cpsi carriers such same overpressure values of $0{,}03 \cdot 10^{-4}$ Pa were recorded. From the considered research point of view such values do not allow to get information necessary for the realisation of the next assumed examination.

Analysing a distribution of pressure in the exhaust system without the catalyst it can be found that for all phases of the test the pressure differences between the p0–p5 points are small (fig. 4). In points p6–p8 which are distant from the point p5 by 60 cm the pressure values are also similar. In every phase, depending on the overpressure values, the measuring points can be separated into two groups of points p0–p5 and p6–p8. In points p6–p8 the overpressure values in every phase are smaller what results from their greater distance from the exhaust collector. The differences in the overpressure values measured in the measuring points of the individual groups can be explained by the pressure fluctuation in the engine exhaust system and an indication error of the applied pressure measuring sensors (fig. 5).

As the distance from the exhaust collector increases the pressure value decreases. In case of measuring points before (p0), in (p1 – p4) and just after the catalysts (p5), the differences in the overpressure values are caused by the exhaust gas flow resistance in the individual catalytic blocks. For every test phase in points distant from the catalyst (p6 – p8) the pressure values are much lower and continue their falling tendency depending on the distance in relation to the exhaust collector.

In case of the catalyst the highest overpressure values were recorded for the phase X at the point p0 and they were of 6,3·10^{-4} Pa for the catalyst equipped with the 200 cpsi carrier.

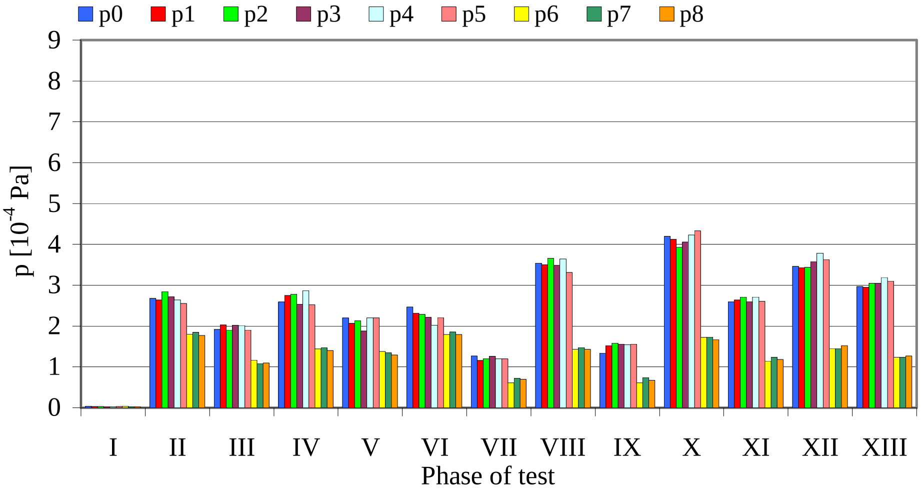

Fig. 4. Distribution of pressure in measurement point p0-p8 exhaust pipe of testing engine without catalytically converter during realization ESC test [3]

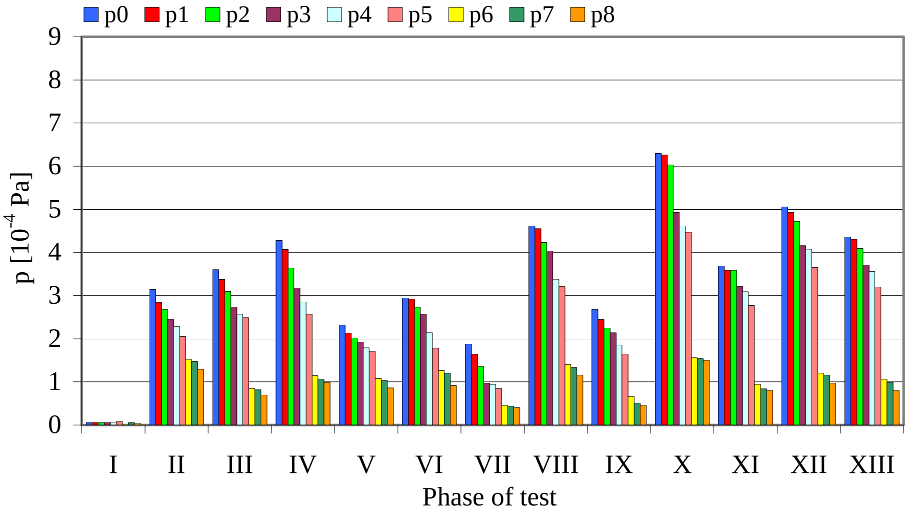

Fig. 5. Distribution of temperature in measurement point T0-T8 exhaust pipe of testing engine with 200 cpsi catalytically converter during realization ESC test [3]

5. Analyses of tested catalytic converter with 200 cpsi

In order to determine the effectiveness of the applied catalytic converter for the reduction of the NO_x emission according to the obligatory official certification test ESC some preliminary examinations of its efficiency under the engine test bend conditions were performed. Taking the operation nature (character) into consideration the NO_x emission in each phase of the test was analysed [3].

To determine the reduction in the NO_x emission the emission measurements were taken after each catalytic block. The presented results are referred to the NO_x concentration values before the catalytic converter**.** The efficiency for the individual catalytic blocks was determined from the relation:

$$k_r = \frac{C_p - C_z}{C_p} \cdot 100\,[\%],$$

where:

C_p –concentration NO_x before catalytic converter, C_z –concentration NO_x after catalytic converter.

Due to the diversified parameters characterising the catalytic converters, which are being built with the use of the catalytic carriers with different cell densities, the examinations were performed for the catalytic blocks based on the carriers with a cell density typical for the compression-ignition engines of 200 cpsi (fig. 6). The application of the catalytic carriers with higher cell densities was considered inadvisable because of a high resistance of flow of exhaust gases intensified by the PM emission.

The operation performance of the catalytic converter with the 200 cpsi carrier is similar in each phase of the test (fig. 7). In phases II-XIII the catalytic converter was characterized by an effectiveness of the reduction in the NO_x emission of 15%. The analysis of the measuring points shows that from the point c3 on the reduction in the NO_x emission level was constant. That means that the catalytic reactor volume is sufficient with reference to the assumed amount of the active layer deposited on each catalytic block. The ratio of that volume to the engine displacement volume was 0.76. The analysis of the bibliographic data shows that this ratio values are in the 0.75-1.3.range.

Fig. 6. Metallic enclosure of tested catalytic converter [3]

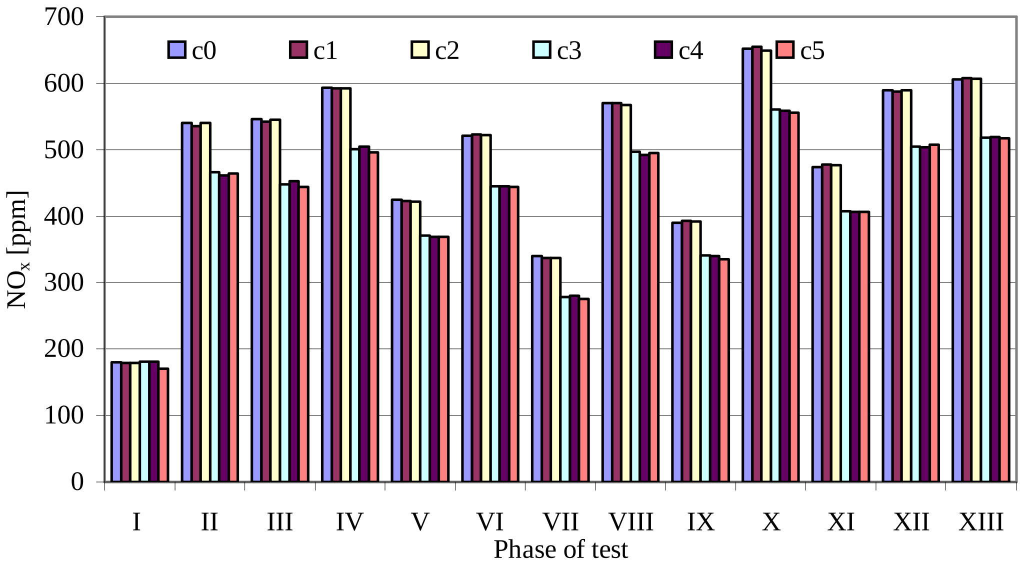

Fig. 7. *Value of NO_x concentration during ESC test of catalytically converter with 200 cpsi [3]*

The emission measurements in points *c6–c8* are considered close to the emission measured in the point *c5*. For the discussed points the difference in the NO_x concentration was at the indication error level of the measuring exhaust gas analyser.

The performed analysis shows that the catalytic converter with the 200 cpsi carrier allows to obtain a satisfactory difference in the voltage signals basing on the NO_x concentration after the third catalytic block. However, it should be noted that the obtained effectiveness of the catalytic converter for the NO_x reduction is unsatisfactory. The average percentage effectiveness of the discussed catalytic converter in the measuring point c5 was 14% (table 1).

Table 1. *Efficiency of limit NO_x concentration [%] behind ever catalytically blocks in light of concentration before catalytically converter (200 cpsi) [3]*

No phase	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
Point c1	0,3	0,8	0,1	-0,3	2	0,3	-1	1	0,3	-10	0,3	10	0,3
Point c2	0,4	-0,1	-0,5	-0,3	2	0,4	-1	1	0,4	-9	0,4	10	0,4
Point c3	-0,8	13	17	15	14	15	16	14	13	5	15	23	14
Point c4	-0,8	14	16	14	15	15	16	14	13	6	15	23	14
Point c5	5	14	18	16	15	15	17	14	15	6	15	22	15

Conclusions

On the basis of the performed examinations and obtained test results the following conclusions can be drawn:

1. The analysis of the NO_x concentrations in exhaust gas from the compression-ignition engine can be based on the indications of the voltage probes with the modified electrodes of the oxygen pump;
2. The application of the reduction conditions in the voltage probes using the nitrogen oxides reduction by the electro-catalytic way depends on the exhaust gas parameters, the values of which change depending on the rotational crankshaft speed and engine load. For this reason obtaining the diagnostic signal for the whole engine operation range is impossible. The control of the correctness of the catalyst operation regarding the nitrogen oxides reduction can be realised for the defined operating parameters of the tested engine;
3. For phases VIII and X of the ESC test the reheating the test probe installed before the catalyst was unnecessary owing to the high exhaust gas temperature (737–759^{o}C).

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Abbreviations

cpsi	*cells per square inch*
EOBD	*European On Board Diagnostic*
ESC	*European Stationary Cycle*
NO_x	*Nitrogen oxides*
OBD II	*On Board Diagnostic II*
OBD	*On Board Diagnostic*
OBDE	*On Board Diagnostic Efficiency*
USPD	*Ultra Spray Pyrolysis Deposition*