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Research Paper

Model-based passive and active diagnostics strategies for diesel oxidation catalysts

C. Guardiola [a], B. Pla [a], P. Piqueras [a], J. Mora [a,*], D. Lefebvre [b]

[a] CMT–Motores Térmicos, Universitat Politècnica de València, Valencia, Spain
[b] PSA Peugeot Citroën, La Garenne-Colombes, France

HIGHLIGHTS

- Validation and error temperature interval of the passive model.
- Oxidation dynamics of a post-injection pulse in terms of CO_2 and temperature.
- Post-injection behaviour with a pulses model to calibrate the diagnosis strategy.
- Diagnosis strategy to discern whether a DOC is able to oxidise or not.

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ABSTRACT

This article proposes a diesel oxidation catalyst diagnostics strategy based on the exothermic process generated by exhaust gas species oxidation in the catalyst. The diagnostics strategy is designed to be applied on-board and respecting real-time electronic control unit computational limitations. Diagnostics purposes are fulfilled by means of the comparison of the passive model temperature, which represents the outlet temperature of a non-impregnated diesel oxidation catalyst, and the measurement provided by the on-board catalyst-out temperature sensor. Thus, the presented diagnostics strategy uses only two production grade temperature sensors and the measurements of air and fuel mass flows from the electronic control unit. Passive diagnostics is based on the oxidation of engine-raw emissions, whilst active diagnostics is based on the oxidation of requested post injected fuel. Post-injection strategy is also discussed for active diagnosis. Then, the diagnostics strategy is able to discern whether the diesel oxidation catalyst is able to oxidise or not.

1. Introduction

Exhaust gases regulation of diesel engines has become more stringent during recent decades. Emission limits have decreased and normative is trying to increasingly approach to real driving conditions [1]. Traditional direct injection combustion engines technology is not able to accomplish regulation limit thresholds with only in-cylinder technology, so aftertreatment systems are necessary to reduce tail-pipe pollutant emissions [2]. However, aftertreatment aging may mitigate its efficiency over time and on-board diagnosis (OBD) should detect defficiencies which increment concentrations of tail-pipe pollutant species [3]. In this article, an OBD strategy is presented for diesel oxidation catalysts (DOC).

Several after-treatment systems are already being used in light duty vehicles. The most commonly used is the diesel oxidation catalyst [4]. Washcoat on the ceramics substrate of diesel oxidation catalysts is generally impregnated with a certain proportion of Pt and Pd. It allows the oxidation of HC, CO and NO species [5], as well as the soluble organic fraction (SOF) of the particulate matter (PM) [6], all present in engine-raw exhaust gases. The DOC is placed between the engine and the rest of aftertreatment systems, since it affects the performance of diesel particulate filters (DPF) during regeneration conditions [7] and selective catalytic reduction (SCR) by reducing the NO/NO_2 ratio [8,9]. Then, a proper operation of DOCs is essential to keep an overall after-treatment efficiency.

Diesel oxidation catalysts are subjected to several permanent and temporary deactivation mechanisms. Main permanent causes are thermal damage, induced by generating exotherm on the catalyst, and exposure to various inorganic species contained in engine

* Corresponding author.
E-mail addresses: carguaga@mot.upv.es (C. Guardiola), benplamo@mot.upv.es (B. Pla), pedpicab@mot.upv.es (P. Piqueras), jamopre1@mot.upv.es (J. Mora), damien.lefebvre@mpsa.com (D. Lefebvre).

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fluids [10]. As an example of a temporary DOC damage, light-off temperature is increased due to an exposure to excessive temperature [11]. Deactivation mechanisms show significant effects on NO and C_3H_6 oxidation [12,13].

The objective of the article is to introduce an on-board real-time diagnostics strategy based on the exothermic generated by the DOC when there is presence of oxidable species, which has to be able to discern whether a DOC is able to oxidise or not. In passive diagnosis, during normal driving conditions, engine-raw emissions are not able to feed the DOC with enough HC [14] to generate enough increment of temperature at the outlet of the DOC. Therefore, post-injections are used in active diagnosis as an extra excitation to increase HC concentration at the inlet of the DOC [15,16]. Post-injections used during DPF active regeneration phases can be also used for DOC diagnostics purposes.

On-board diagnosis approaches must take into account the limitations of on-board applications, since sensors are limited in commercial vehicles and models must respect the computational resources of the electronic control unit (ECU). Thus, signals used as inputs to the strategy are the DOC-inlet and outlet temperatures, the air mass flow and the fuel mass flow. Then, no estimation of HC, CO nor NO concentrations is done as far as no sensor is to be used in real world vehicles and there is also difficulty of modelling them. Finally, the control-oriented model used in this work to estimate temperature can be found in [17].

Paper is structured as follows. Section 2 describes the experimental set-up and presents the sensors used. Section 3 presents the general diagnostics strategy. Section 4 discusses the post-injection strategy approach. Finally, conclusions are presented in Section 5.

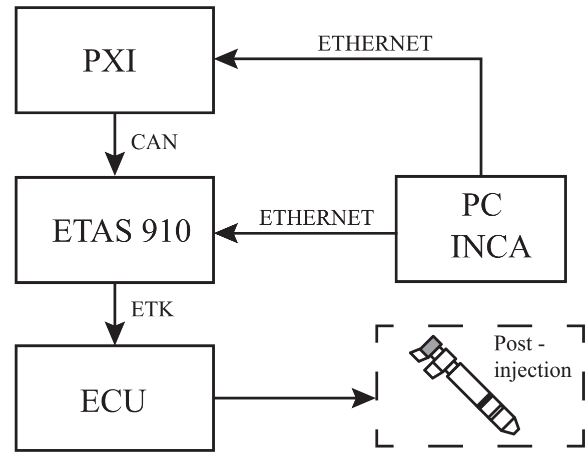

Fig. 1. Scheme of the bypass performed to the engine ECU with post-injection purposes.

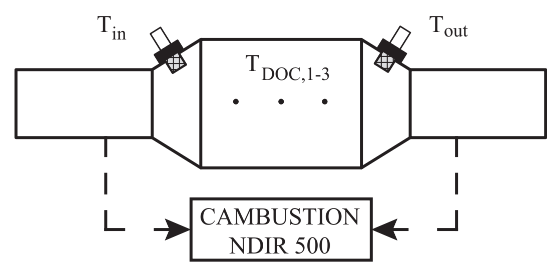

Fig. 2. DOC instrumentation layout.

2. Experimental setup

The engine used in this study is a common light-duty engine equipped with a high pressure common-rail fuel injection system, a variable geometry turbine and a high pressure exhaust gas recirculation system. A DOC was the only aftertreatment device in the exhaust line, in company with a back pressure valve to substitute the pressure drop effect of a DPF. A pair of different DOCs, listed in Table 1, have been tested. On the one hand, a DOC with washcoat, named nominal DOC, is able to perform oxidation of the different species and accumulate HC [18,19]. It is used to represent the behaviour of a new DOC. On the other hand, a DOC without washcoat, named non-impregnated DOC, is used in order to calibrate the model. This DOC does not have any oxidation capability, so it is only able to behave as a regenerative heat exchanger.

A bypass was done to the ECU of the engine through an ETAS 910 and a National Instruments Real Time PXI, mainly in order to post-inject raw fuel when necessary, as sketched in Fig. 1. Different acquisition sensors, shown in Fig. 2, were installed along the exhaust line and the DOC. Three thermocouples measure DOC core temperature at different sections in the axial direction. Two Denso negative temperature coefficient (NTC) sensors are installed to measure temperature at the inlet T_{in} and the outlet T_{out} of the DOC. The Denso sensors used are able to measure a range of temperatures from −30 to 1000 °C, with standard responsiveness, according to the sensor manufacturer. This kind of sensors are installed in commercial vehicles, therefore their response and precision will be such as the measurement that will feed the ECU. A Cambustion NDIR 500 was used to have a fast measurement of CO_2, which response time is around 10 ms. As the general dynamics of the system are in the order of magnitude of seconds, measurements read by this fast gas analyser can be understood as non-delayed values of the gas concentration. Thermocouples were connected to a PUMA measuring system, while the two NTC temperature sensors and the Cambustion NDIR 500 were connected to the PXI through an analogic connection.

The origin of the inputs used in the diagnostics strategy are presented in this paragraph. The measurement of the intake air mass flow is captured by a flowmeter located at the intake manifold of the engine. The value of the fuel injected, including post-injection conditions, is given by the look-up tables depending on injection duration and rail pressure. In order to obtain the total exhaust mass flow, the values of the air mass flow and the fuel injected are summed. The two NTC sensors provide the temperature of the exhaust line before and after the DOC. Thanks to the low number of inputs of the model, error due to measurements can be kept low. NTC sensors present an error of ±7 °C at mid temperatures and of ±10 °C at low and very high temperatures, according to the sensor manufacturer. As reported by [3], flowmeter error is in the order of magnitude of 3%. The combined error of sensors and injectors depend on the engine used for the final implementation.

Table 1
DOCs used in the experiments and its main characteristics.

DOC	Ceramics configuration
Nominal	With washcoat
Non-impregnated	Without washcoat

3. General diagnostics strategy

The diagnostics strategy is based on the exothermic reactions caused by DOC activity, mainly due to the oxidation of HC and CO. Thus, when the DOC is oxidising, the outlet temperature increases with respect to the temperature that a