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Experimental assessment of a pre-turbo aftertreatment configuration in a single stage turbocharged diesel engine. Part 2: Transient operation

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ABSTRACT

This paper corresponds to the second part of a work devoted to analyse the impact of the pre-turbo aftertreatment configuration on the performance of a single stage turbocharged Diesel engine. This second part focuses on the analysis of the engine response under transient operating conditions. To address the causes and effects of the change in engine response several types of transient processes consisting of driving cycles and load transient tests have been evaluated as starting point of the analysis.

These tests make possible to account for the influence of the aftertreatment thermal inertia and how it affects the engine and aftertreatment performance obtained during driving cycles and under highly demanding transient operation. The pre-turbo aftertreatment placement also provides advantages in terms of faster aftertreatment warm-up. Therefore, the benefits on DPF (diesel particulate filter) passive regeneration as well as DOC (diesel oxidation catalyst) light-off leading to lower gas emissions have been assessed. The results have been compared against baseline emissions measured during experiments with post-turbo aftertreatment placement. Finally the influence of the thermal inertia on driveability in sudden accelerations as a function of the wall temperature along the exhaust line and boosting architecture is assessed combining the analysis of experimental and modelled data.

1. Introduction

The response of turbocharged Diesel engines under transient operation is a topic of maximum interest for manufacturers and researchers because of its relation with real driving conditions, which are usually falling into the off-design range [1], with important influence on performance and pollutant emissions [2].

The automotive industry is conducting important efforts to the research of the engine transient operation by considering different types of transient patterns, whose main intention is to reproduce properly the real operating conditions of the engine. Driving cycles are the basis for the assessment of the influence on engine performance and pollutant emissions of the combustion process [3], fuel characteristics [4], engine mapping [5], etc. Current efforts are driven to the definition of methodologies, based on microtrips [6] and data-driven approaches [7], to update type-approval driving cycles, like the NEDC (New European Driving Cycle), in order to account for more real driving dynamics. Sudden accelerations and decelerations associated to aggressive driving patterns are usual and have become design objective of future cycles. It is the case of the WLTP (World-Harmonised Light-Duty Vehicles Test Procedure) or RDE (Real Driving Emissions) tests [8]. Load transient tests at constant engine speed constitute a type of test involving highly demanding conditions in terms of turbocharger response [9]. As driving cycles, the analysis of load transient processes at constant engine speed is key in the manufacturing and research activity. The focus is put on noise [10] and pollutants [11] generation including fuel blends influence [12], methodologies for combustion characterisation from experimental [13] and modelling [14] approaches and the influence of engine mapping-control for pollutant standards compliance [15]. The turbocharger lag also results critical in tip-in processes with effects on engine driveability [16] and on the peak value of pollutant emissions [17].

Under steady-state operating conditions, modelling [18] and experimental [19] studies regarding pre-turbo aftertreatment configurations have proved that the engine performance is positively affected by the reduction in aftertreatment pressure drop. This pressure drop reduction and its new location gives rise to

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Table 1
Main characteristics of the engine.

Type	HSDI diesel passenger car engine
Displacement	1997 cm^3
Bore	85 mm
Stroke	88 mm
Number of cylinders	4 in line
Number of valves	4 per cylinder
Compression ratio	18:1
Maximum power @ speed	100 kW @ 4000 rpm
Maximum torque @ speed	320 Nm @ 1750 rpm

lower dependence of control parameters on DPF soot loading [20] in contrast with post-turbo aftertreatment placement [21]. However the heat losses taking place across the aftertreatment elements affect negatively. The pulse amplitude reduction across the aftertreatment system is also an additional phenomenon that reduces the instantaneous power at the turbine inlet. Nevertheless, it may benefit from an optimum turbocharger matching in terms of turbine efficiency [22].

Under transient operating conditions, it is necessary to account for the thermal inertia of the aftertreatment substrate on the turbocharger response. The first studies concerning the influence of pre-turbo aftertreament placements under transient operation were carried out during the 80s. An important delay during accelerations from steady-state idle conditions was found [23]. The need to reduce the thermal inertia led to approach low volumes of knitted fibres obtaining a satisfactory engine response at the expense of reducing the filtration efficiency [24].

Recently, several modelling studies with pre-turbo aftertreatment location have confirmed a reduction in turbocharger lag due to the thermal aftertreatment inertia when the engine is subjected to highly dynamic processes being previous conditions of medium–high load [18]. The substrate acts as an energy source heating the cold exhaust gases which come from the cylinders during the low load phase so that the turbocharger speed reduction is avoided and the turbocharger lag disappears in the subsequent acceleration. Nevertheless, there is a noticeable delay in the turbocharger response with pre-turbo aftertreatment configurations under cold wall operation in single stage turbocharged engines [25]. It has driven to approach for the combined use of this kind of solutions with two stage turbocharging architectures. Bermúdez et al. [16] performed a study with a two stage turbocharged HD Diesel engine obtaining successful results in engine driveability by properly managing the boost and EGR (exhaust gas recirculation) valve control during the transient process.

The aim of this work is to cover the lack of experimental data and analysis on the transient response of turbocharged Diesel engines with pre-turbo aftertreatment configuration. The engine response is analysed during the NEDC and load transient tests at constant engine speed. The results of the pre-turbo aftertreatment configuration are compared to that obtained with the traditional post-turbo aftertreatment placement. The influence of the engine thermal conditions is also considered by imposing different initial conditions to every test. On the one hand, it allows evaluating the benefits on aftertreatment warm-up that the pre-turbo aftertreatment placement provides in terms of DPF passive regeneration and DOC light-off during the NEDC. On the other hand, it provides a complete framework to assess the effects of the aftertreatment thermal inertia. In the last part of the paper, a gas dynamic modelling of the engine response under load transient operation at constant engine speed is performed considering the inclusion of a mechanical compressor as a part of the boosting system. A comparison against the experimental data obtained with the single stage turbocharging architecture is performed with both pre-turbo and post-turbo aftertreatment system locations.

2. Experimental setup

The study under transient operation has been performed with the same engine and test cell facility that in Part 1 of the work, which is devoted to steady-state operating conditions [19]. Table 1 summarises the main characteristics of the engine in which the tests have been carried out. It is a single stage turbocharged Diesel engine for passenger car applications fulfilling emission standards Euro 4.

Fig. 1 shows a scheme of the experimental setup and instrumentation used in the test campaign. The scheme is referred to the

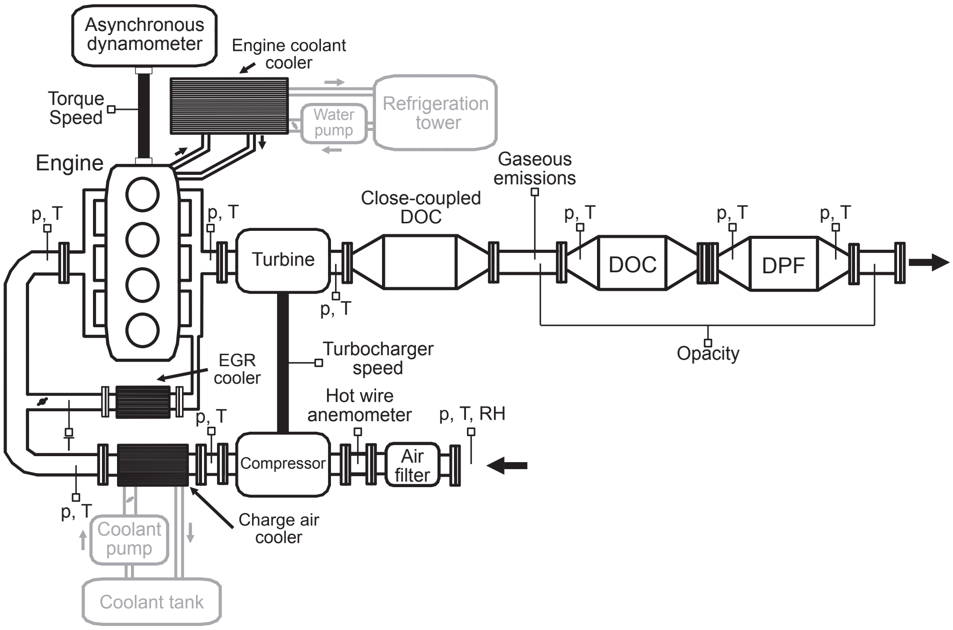

Fig. 1. Scheme of the experimental setup and instrumentation location with post-turbo aftertreatment placement.