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ScienceDirect

Energy Procedia 101 (2016) 670 – 676

Energy Procedia

71st Conference of the Italian Thermal Machines Engineering Association, ATI2016, 14-16 September 2016, Turin, Italy

Air-Fuel ratio estimation along Diesel engine transient operation using in-cylinder pressure

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Abstract

The increasing competition among automotive OEMs together with the worsening of the environmental pollution has lead to the development of complex engine systems. Innovative control strategies are needed to simplify and improve the Engine Management System (EMS), moving towards energy saving and complying with the restrictions on emissions standards. In this scenario the application of methodologies based on the in-cylinder pressure measurement finds widespread applications. Indeed, the in-cylinder pressure signal provides direct in-cylinder information with a high dynamical potentiality that is fundamental for the control and diagnosis of the combustion process. Furthermore, the in-cylinder pressure measurement may also allow reducing the number of existing sensors on-board, thus lowering the equipment costs and the engine wiring complexity.
The paper focuses on the estimation of the Air-Fuel ratio from the in-cylinder pressure signal. The methodology is based on the analysis of the statistical moments of the pressure cycle and was already presented by the authors and applied to a set of steady state engine operation conditions. In this paper the technique has been enhanced in order to be applied under the more critical engine transient operation. The results achieved show a satisfactory accuracy in predicting the Air-Fuel ratio during engine transients performed at the engine test bench on a Common-Rail turbocharged Diesel engine.

Peer-review under responsibility of the Scientific Committee of ATI 2016.

Keywords: In-cylinder pressure; air-fuel ratio; diesel engine; combustion control.

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Peer-review under responsibility of the Scientific Committee of ATI 2016.
doi:10.1016/j.egypro.2016.11.085

1. Introduction

Recently many complex engine subsystems and control technologies have been introduced to meet the demands of strict regulations and the competitive market too. Anyway, for diesel engines, combustion control is one of the most effective approaches for reducing not only engine exhaust emissions but also cylinder-by-cylinder variation and engine consumption, because of the large amount of control variables to be managed. For these reasons, innovative control strategies appear as the best solution for vehicle manufacturers in order to achieve cleaner and energy saving engines. With this aim a large number of actuators and sensors are used, both in steady-state and transient operations, in order to monitor engine states and outputs. Otherwise most of information provided by the sensors can be extracted from the in-cylinder pressure trace.

Studies about the 'Pressure-Based' Control (PBC) started since the sixties, but the first application in commercial cars was only between 1980 and 1990 [1] . The reader is addressed to Powell [2] , who was the first author to propose a pressure-based algorithm for the estimation of the air-fuel ratio and misfire detection on spark ignition engines. In 1995 Leonhardt implemented a closed loop control on the injection pattern [3] , by means of a neural network based on specific combustion metrics extracted from the pressure cycle. In 1999 Tunestal instead [4] , improved the cold start on Diesel engine and Mladek, one year later, developed an innovative technique for the estimation of the in-cylinder trapped mass [5] . More recently the application of pressure based methodologies has been oriented to Diesel engine control for virtual sensing of NO_x and PM emissions [6] [7] .

This work focuses on the estimation of the air-fuel ratio in a Common-Rail turbocharged Diesel engine based on the statistical moments of in-cylinder pressure cycle. The in-cylinder AFR estimation allows improving the closed-loop control of the injection pattern and the air path, with benefits on engine emissions and fuel consumption especially during cold starts and transient operations. Indeed, the in-cylinder AFR estimation allows avoiding the gas inertia effects and the time delay that typically affect the measurement provided by the UEGO sensor. The technique has been already presented and applied by the authors on two different automotive Diesel engines, by processing the in-cylinder measurements collected in steady-state conditions [8], [9] . In the current study, the technique has been enhanced to be applied under engine transient operations that are of course of greater interest to test the feasibility of the on-board application. Suitable procedures have been introduced to improve model identification by processing the raw pressure measurements and by detecting the parameters that are mostly correlated to the AFR.

Nomenclature

a_n, b_n	n-th regression constant [/]
AFR	Air-Fuel ratio [/]
ATDC	After Top Dead Centre [deg]
CAD	Crank Angle Degree [deg]
EGR	Exhaust Gas Recirculation
EMS	Engine Management System
EOC	End of Combustion [deg]
m	Polytropic index in non-adiabatic condition [-]
M_{nn}	Normalized statistical moment of order n
N	Engine speed [rpm]
$p(\theta)$	In-cylinder pressure [bar]
PBC	Pressure-Based Control
R2	Correlation index [/]
SOI	Start of Injection [deg]
TDC	Top Dead Centre
V	Actual displaced volume [m3]
VGT	Variable Geometry Turbine
θ_c	Centroid crank angle [deg]