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Accelerometer Based Methodology for Combustion Parameters Estimation

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Abstract

Due to increasingly stringent emission regulations and the need of more efficient powertrains, obtaining information about combustion process becomes a key factor. Low-cost in-cylinder pressure sensors are being developed, but they still present long-term reliability issues, and represent a considerable part of the engine management system cost. Research is being conducted in order to develop methodologies for extracting relevant combustion information using standard sensors already installed on-board. The present work introduces a methodology for combustion parameters estimation, through a control-oriented analysis of structure-borne sound. The paper also shows experimental results obtained applying the estimation methodology to different passenger car engines.

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Keywords: gasoline engine, diesel engine, control, accelerometer signal, in-cylinder pressure signal, combustion parameters, closed-loop control, spark advance, start of injection.

1. Introduction

In order to comply with most recent emission regulations, it has been already widely demonstrated by many researchers that a significant reduction of pollutant emissions can be achieved by using closed-loop combustion control, based on real time in-cylinder pressure analysis [1,2,3].

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Cost and long-term reliability of in-cylinder pressure sensors still represent the main issues towards the on-board implementation of closed-loop combustion control algorithms. Even if the poor sensors' reliability is overcome in the future, they will still represent an important rate of the overall control system's cost. Due to these reasons, many methodologies to estimate fundamental combustion parameters, based on transducers already mounted on-board, are available in scientific literature. For example: in-cylinder pressure reconstruction from torque sensor [4], analysis of crankshaft speed fluctuations [5,6,7] or structure-borne sound using vibration transducers [8].

The paper presents a methodology to extract useful information for combustion phasing closed-loop control, based on vibration signal analysis. This approach has been applied on both gasoline and diesel engines; the use of on-board vibration signal information is a widespread solution adopted for knock onset detection in gasoline engines [9], whereas in the diesel application is not as common, but its introduction would not result in an unacceptable cost increase.

The development of a control system able to detect the combustion phase within the engine cycle, would enable the engine efficiency (or the engine torque) to be maximized. Indeed, it is well known that the torque output of an engine is strongly correlated to the combustion phase. Many parameters can be defined to represent the combustion phase: the most commonly used are the Pressure Peak Position (PPP) and the Center of Combustion (CA50), which is defined as the crankshaft angle where the 50% of fuel mass is burned. The combustion phase and the previously mentioned efficiency-related parameters, are influenced by spark advance (for spark ignition engines), and by the start of main injection (for compressed ignition engines). Therefore, knowing these quantities would enable the implementation of a closed-loop combustion control system. Figure 1.a and 1.b show some experimental results, for the gasoline engine used in this work, in which the normalized Indicated Mean Effective Pressure (IMEP) is represented versus PPP and CA50.

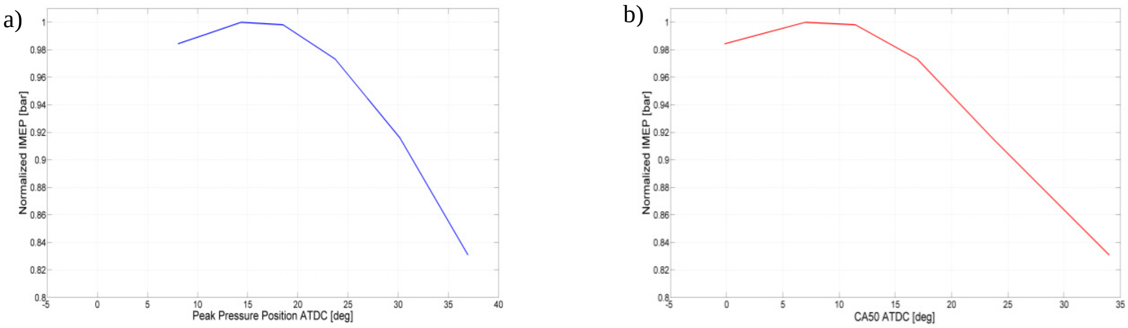

Figure 1. IMEP versus PPP (a) and IMEP versus CA50 (b). Spark ignition engine.

The two combustion phase parameters taken into account have interesting properties; the values they assume when maximizing the IMEP can be considered to be constrained in a narrow range, similar for every engine and essentially constant through the overall operating range. These properties are demonstrated from experimental experiences and can be used to identify a target value. The typical crank angle in which the peak pressure must be placed to achieve the maximum torque output is about 16 deg. after TDC (Top Dead Center), as shown by Hubbard et. al. [10], while for the CA50, the optimal position is about 10 deg. after TDC, as shown by Heywood [11].

Typically, in commercial ECUs, the combustion phase parameters are not calculated, since this implies the need to directly measure the pressure inside the combustion chamber. The development of alternative ways to estimate these quantities using non-intrusive methodologies or sensors already installed on-board, would avoid increasing the production costs, the design complexity and the long-term reliability issues related to the use of in-cylinder pressure sensors. This paper represents a first attempt to explore the possibility of estimating combustion phase parameters such as PPP, by means of real-time processing the vibration signal.