Engine knock detection: an eigenpressure approach

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Abstract: In this work a knock detection approach based on in-cylinder pressure principal component analysis is proposed. The introduction of a set of basis functions called eigenpressures - used to describe the principal components of the pressure traces - allows for an easy and effective separation between the typical "bell shape" component of pressure profiles and the knock-induced pressure oscillations, making possible the classification of knocking and not knocking cycles. The proposed approach is compared to a standard knock detection method based on the in-cylinder pressure trace band-pass filtering and to a pure data-driven algorithm. The method shows the best knock classification performances and proves to be advantageous thanks to the low number of easily tunable parameters and their ease of calibration/interpretation.

Keywords: Engine knock, Engine control, Principal Component Analysis, Classification

1. INTRODUCTION

In the spark ignited engine technology, knocking phenomenon is recognized as an undesirable event caused by unburnt gasoline/air mixture self-ignition (Heywood et al. (1988)), and is capable of causing serious engine damages. In the pursue of higher performances and efficiency, production engines underwent to a significant increase of their compression ratio which, unfortunately, leads also to higher end-gas temperatures and pressures, increasing susceptibility to knock (Hudson et al. (2001)). In this context, fuel octane number and spark ignition control come to hand in order to mitigate the knocking behavior: closed-loop strategies have been developed in order to counteract to knock events and operating conditions modification, see *e.g.* Kiencke and Nielsen (2005); Jones et al. (2009).

In order to develop a closed-loop control strategy, detection of abnormal combustion and knock intensity is a crucial aspect. According to Zhen et al. (2012), knock detection can be achieved by means of different methodologies based on the analysis of in-cylinder pressure, engine block vibration, ionization current (Kinoshita et al. (2000)), exhaust gas temperature (Abu-Qudais (1996)) and heat transfer (Worret et al. (2002)). Above all these methods, those based on the investigation of (a) pressure and (b) vibrations are the most common and well-known. The former approach (a) generally relies on band-pass filtering of in-cylinder pressure profiles in order to extract the high frequency signature typical of knocking events, as shown by Millo and Ferraro (1998); Puzinauskas (1992)). Based on these filtered signals, knock indicators such as per-cycle energy, Maximum Amplitude of Pressure Oscillations ($MAPO$) or Logarithmic Knock Intensity (LKI) (Hudson et al. (2001)) may be adopted. The latter approach (b) is based on the idea that end-gas self-ignitions cause vibrations of the engine block which can be studied by means of accelerometers, as proposed by Millo and Ferraro (1998); Pipitone and D'Acquisto (2003). After band-pass filtering the vibration measurements, knock indicators such as root mean square of filtered signals or maximum oscillations amplitude may be computed. Generally, this is a relatively low-cost approach, practical for mass-production vehicles. For both the aforementioned methods, engine cycles are classified as knocking or not knocking depending on whether the computed indicators are exceeding some thresholds or not.

In this paper, a knock detection technique based on in-cylinder pressure Principal Component Analysis (PCA) is proposed. The main idea is the description of pressure profiles by means of a restricted set of eigenvectors - called eigenpressures - computed relying on PCA over experimental pressure data. This allows for a clear separation between the typical "bell shape" component of pressure traces and the knock-induced pressure oscillations, making detection of knocking cycles easier. One of the major advantages of this methodology is the low number of tuning parameters which can be easily adjusted without the need of a complex pressure traces spectral analysis. Moreover, the proposed approach is prone to an easier interpretation and prediction of the knock detection perfor-

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