Engine knock margin estimation using in-cylinder pressure measurements

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***Abstract*—Engine knock is among the most relevant limiting factors in the improvement of the operation of spark ignited engines. Due to an abnormal combustion inside the cylinder chamber, it can cause performance worsening or even serious mechanical damage. Being the result of complex local chemical phenomena, knock turns out to have a significant random behaviour but the increasing availability of new on-board sensors permits a deeper understanding of its mechanism. The aim of this paper is to exploit in-cylinder pressure sensors to derive a knock estimator, based on the logistic regression technique. Thanks to the proposed approach it is possible to explicitly deal with knock random variability and to define the so-called *margin* (or *distance*) from the knocking condition, which has been recently proven to be an effective concept for innovative knock control strategies. In a model-based estimation fashion, two modelling approaches are compared: one relies on well-known physical mechanisms while the second exploits a principal component analysis to extract relevant pressure information, thus reducing the identification effort and improving the estimation performance.**

***Index Terms*—Engine knock estimation, knock control, in-cylinder pressure sensors, logistic regression, principal component analysis**

I. Introduction and Motivation

THE combustion process in SI engines is normally triggered by the spark, whose timing is accurately defined in order to achieve the desired engine performance. In particular engine operating conditions, a too early spark timing may cause an abrupt unburned mixture (end-gas) self-ignition, due to the high temperature and pressure conditions reached inside the cylinder chamber. This event is usually termed *knock*, recalling the typical metallic sound caused by the shock waves generated by the spontaneous detonation of the air/fuel mixture. Such event limits the improvement of engine performance, being responsible for some undesirable effects: while it can cause serious cylinder damages, less dramatic consequences are powertrain oscillations, a general decrease of engine efficiency and an increase of pollutant emissions [1]. An accurate control of SI timing has thus lately become a crucial issue in the development of advanced combustion control systems.

In the scientific literature specific attention has been paid to the knock event due to its applicative relevance. The air/fuel self ignition is the result of complex local phenomena in the cylinder chamber and as such shows significant experimental random nature. For this reason, the first research efforts have been devoted mainly to knock sensing and detection [2], [3], with the development of techniques and technologies that, flanked with efficient signal processing algorithms, could be able to reliably discriminate knocking from not knocking cycles (and, if possible, to quantify the detonation severity).

Knock control strategies developed consequently: the standard approach, which has been widely adopted in series production, can be classified as event-based where, based on simple [4] or more complex [5] rules, a single measured knock occurrence causes a controller intervention. In order to cope with knock random nature, stochastic knock control strategies have been recently proposed. Their main idea is to compare the statistic knock properties of the current engine operating point (rather than considering each event individually) with a target value and to adapt the control action accordingly. In [6] the feedback statistic is established as a cumulative sum of knocking events over a certain number of cycles, whereas in [7] a likelihood ratio approach is employed. In [8] a nonlinear transformation is used to shape the random distribution of the knock events as a Gaussian variable whose mean and variance are recursively estimated and used as feedback signals for the knock control strategy. The advantage of stochastic approaches is the fact that reckoning with the stochastic knock behaviour leads to better mean engine running conditions and to less cyclic variability. The drawback of the mentioned strategies lays in the fact that the feedback statistic signal is built in real-time, which requires several cycles. Given a single engine cycle, out of the current operating point history, no statement about the expected knock rate is possible.

The control strategy proposed by Lezius et al. in [9] approaches the problem differently. It is based on the evidence that cycles with a higher peak pressure are more likely to knock. Engine knock is thus closed-loop regulated tracking a peak pressure reference that is a compromise between engine output torque and engine knock tendency. The distinguishing feature of this approach is the fact that a *margin* (or *distance*) from the knocking condition is defined for any single cycle. In this specific case the cycle peak pressure is used to estimate engine knock and its distance, computed as the error between the measured and the target peak pressure value.

Proper models are required to design such a knock margin estimator. In Lezius' work, the model is implicitly enclosed in the experimental evidence of a more frequent knock occurrence for higher peak pressure cycles. With respect to the real-time stochastic approaches described previously, the additional modelling effort compensates for the advantage of a cycle-to-

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