Engine knock margin control using in-cylinder pressure data: preliminary results

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***Abstract*— Knock is an undesired phenomenon occurring in spark ignited engines and is controlled acting on the spark timing. This paper presents a closed-loop architecture that addresses the knock control problem in a standard model-based design framework. An engine knock margin estimate is feedback controlled through a PI controller and its target value is computed on the desired knock probability. A black-box modelling approach is used to identify the dynamics between the spark timing and the knock margin and a traditional model-based controller synthesis is performed. Experimental results at the test bench show that, compared to a conventional strategy, the proposed approach allows for a better compromise between the controller speed and the variability of the spark timing. Moreover, another advantage w.r.t the conventional strategies is that closed-loop performances prove to be constant for different reference probabilities, leading to a more regular engine behaviour.**

I. Introduction

Knock is a limiting phenomenon in spark ignited engines; it is the autoignition of the end gas in the combustion chamber which generates large pressure oscillations [1] causing potential engine damages and performance decreases. However, in order to maximize the engine efficiency, in particular on low speed and high torque operation, the engine needs to run close to the knocking condition: thus a closed loop knock margin regulation, acting on the spark timing, is a crucial component.

The scientific literature has dedicated considerable effort to the problem of knock sensing and knock control. While the detection of knock events is a relatively easy task [2]–[5], the control part is more challenging. Due to the stochastic behaviour of engine knock and its binary nature (*i.e* an engine cycle knocks or not), the use of classical standard control strategies is limited and not-trivial. Strategies proposed in literature can be divided in two groups: those controlling properties of knock, derived by knock occurrence and others controlling a knock-related (usually model-based) metrics.

Among the strategies controlling the stochastic properties of knock events, the most simple one is referred to in literature as the conventional strategy. It consists of rapidly retarding the spark timing if a knock event is observed, and slowly advancing the timing during non-knocking cycles [6]. Due to its easy implementation and tuning, the conventional knock controller is widely used in industrial applications. However, it results in a late average (*i.e.*, low efficiency) and a high variance of the spark timing. More advanced methods monitor the cumulative summation of knock events and compare it with the desired knock rate [7], [8]. Instead of acting at each knock event, those controllers retard the spark timing when the difference between the observed and the desired knock rate exceeds a positive threshold and advances the spark timing when the difference falls below a negative threshold. The methods proposed in [7] and [8] use fixed amplitudes of the retarding and the advancing actions. A further improvement can be made by relating the action intensity to the discrepancy between the observed and the desired knock rate: the likelihood ratio is an indicator of this discrepancy and is employed in [9]. The so-called likelihood-based approach shows satisfactory results on both simulation end experimental data [10]. Although effective, advanced stochastic knock controllers rely on non-standard tuning procedures, have a delayed transitory response and present a sub-optimal trade-off between the controller speed and the steady-state variability of the spark timing.

Due to the difficulty of modelling the combustion inside a cylinder chamber, methods based on the control of a knock-related metrics are less developed. The most trivial knock metric is the cycle peak pressure [11]. Cycles with higher peak pressures are more likely to result in knock, thus the maximum pressure can be controlled at a reference value that is a compromise between the engine torque output and the knock tendency. Another possibility consists in quantifying the knock intensity through the engine casing acceleration to build a knock energy indicator controlled via a proportional integral (PI) controller [12]. However, the estimation of the mean and the variance of the energy indicator slows the controller action.

The knock control strategy proposed in this paper is based on the estimation approach introduced in [13], where the authors build a gray-box model of the knock margin that proves to effectively extract important information from the cylinder pressure traces and describes the knock behaviour in various engine operating conditions, outperforming more traditional physics-based approaches. The estimator provides, for each engine cycle, the knock margin (*i.e.* the distance from knocking conditions) and an estimate of the expected

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