Adaptive and Unconventional Strategies for Engine Knock Control

Donald Selmanaj, Stijn van Dooren, Giulio Panzani, Jonatan Rosgren and Christopher Onder

***Abstract*—Knock is an undesirable phenomenon affecting gasoline spark-ignition (SI) engines. In order to maximize engine efficiency and output torque while limiting the knock rate, the spark timing should be adequately controlled. This paper focuses on closed-loop knock control strategies. The proposed control strategies, compared to conventional approaches, show an improved performance while remaining simple to use, implement, and tune. First, a deterministic controller which employs a logarithmic increase of the spark timing proves to outperform the conventional strategy in terms of spark timing average and variance. Second, a stochastic adaptive strategy that is meant to assist the deterministic controller is introduced. Due to this extension, the average and the variance of the spark timing are improved while preserving the easy tuning and the fast reaction times of the deterministic strategy. Throughout the paper, all the knock controllers are compared with a conventional deterministic strategy and with a recently proposed stochastic one. The advantages of the proposed approaches are confirmed both by simulation and by experimental data collected at a test bench.**

***Index Terms*—knock control, SI engines, engine knock.**

I. INTRODUCTION

The phenomenon of knock is a major limitation for SI engines. Knock has its name from the audible noise that results from autoignitions in the unburned part of the gas. It causes undesired pressure oscillations in the combustion chamber. In order to avoid knock, the engine has to be run in a sub-optimal way with respect to efficiency. In addition to limiting the compression ratio and lowering the levels of pressure and temperature, preventing knock requires the spark timing to be delayed [1]. Closed-loop knock control systems acting on spark timing are thus crucial in order to maximize the engine efficiency while limiting the knock rate.

Knock sensing is a key component for knock control systems. On the one hand, considerable research efforts have been dedicated to the problem of knock detection [2]–[5] by processing different types of measurements to produce knock metrics [6]–[15]. On the other hand, knock control strategies have received less attention. The most trivial strategy consists of rapidly retarding the spark timing if a knock event is observed, and slowly advancing the timing during non-knocking cycles [16]. This strategy is referred to in literature as the conventional knock control strategy and is widely used in industrial applications. The conventional strategy is easy to implement and tune, but it results in late average and a high variance of the spark timing.

More advanced methods are based on the concept of margin (or distance) from the knocking condition. Instead of acting on knock events, these approaches relate the knock intensity to measurement data obtained during non-knocking cycles. The most evident measurement related to knocking is the cycle peak pressure [17]; cycles with higher peak pressures are more likely to result in knock. The authors model the relation between knock intensity and peak pressure and control the latter at a reference value that is a compromise between engine torque output and knock tendency. Exploiting the same philosophy, in [18], the authors build a gray-box model of the knock margin that proves to effectively describe the knock rate in various engine operating conditions, outperforming more traditional physics-based approaches. While both approaches are effective, they require a considerable modeling effort and do not consider engine aging, which also can change the relation between measurement data and knock intensity.

The majority of the scientific literature is based on the control of the statistical properties of the knock phenomenon. These methods are referred to as "stochastic" knock controllers. Instead of controlling a knock margin or acting on knock events, these methods control the statistical properties of a knock intensity metric. One possibility consists of quantifying the knock intensity through engine casing acceleration to build a knock energy indicator controlled via a proportional integral (PI) controller acting on the spark timing [19]. The method requires the estimation of the mean and the variance of the acceleration signal energy which slows the controller action. Similar approaches based on the statistical properties of knock intensity [20] and combustion stability [21], aim at improving controller responses by adding fast control actions.

An alternative approach consists of modeling and controlling the statistical properties of knock events based on the comparison of the knock intensity metric with a calibrated threshold [16]. This approach neglects the knock intensity information and uncouples the latter from the control action intensity, but it simplifies the modeling of the knock phenomenon as knock events can be modeled by simple statistical (e.g., binomial) distributions whose characteristics are functions of the spark timing. Based on this philosophy a controller that monitors the cumulative summation of knock events and compares it with the desired knock rate is proposed

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