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Knock detection in spark ignition engines by vibration analysis of cylinder block: A parametric modeling approach

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Abstract

A simple and novel method for detection of low intensity knock, occurred in spark ignition engines, is developed in this paper. The proposed method is based on the modeling of the cylinder block vibration signal by auto regressive moving average (ARMA) parametric model. It is observed that one of the estimated moving average parameters is highly sensitive to the knock, so by monitoring this parameter, it is possible to detect the knock in SI engines even in very initial stages. The results also demonstrate that the proposed method is capable of detecting knock by simple hardware with low sampling frequency, leads to reduction the computation time as well as hardware complexity and cost. Moreover, a new method of utilizing the tachometer signal in parallel to the accelerometer one to estimate the knock-sensitive window (KSW) is introduced.

Keywords: Spark ignition engines; Engine knock; ARMA model; System identification

1. Introduction

Engine knock is a knocking or pinging sound, sometimes may be heard from an operating engine. A rapid auto-ignition of a portion of the fuel mixture in the cylinder generates a local pressure pulse, leading to pressure oscillations, propagating across the cylinder. These oscillations create noise outside the engine, which is called "knock" [1]. Knocking in engine has some unfavorable effects such as increase in engine pollution, decrease in engine efficiency, considerable rise in engine specific fuel consumption (SFC) and possibility of structural harms to engine in a long-term period. Thus, detection and prevention of this problem is of high importance. The approaches, applied in knock detection can be classified into two broad categories namely direct and indirect approaches. The former one is based on the direct measurement and study of inside cylinder parameters, which can be influenced by knock. One instance in this field is a set of experiments done by Hudson et al. [2]. In this research, they analyzed inside cylinder pressure signals to study directly the inside combustion chamber processes, which are influenced by knock. However, direct measurement of the inside combustion chamber parameters has some major drawbacks, for instance the sensors installed inside

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the cylinder chamber are in direct contact with hot and high pressure mixture, consequently these sensors have short lifetime expectancy and low accuracy except the very expensive ones. Also, the sensors and their insertion points would influence inside mixture regimen, which is under study. In addition, necessity of using too many sensors (one set for each cylinder) not only increases process cost but also complicates employed hardware and software. For these and other problems which restrict the applicability of direct methods, at least in industrial scales, the indirect approaches were developed. The indirect methods are based on studying solely the outside cylinder knock-sensitive parameters such as engine noise and/or cylinder block vibration. This is rather an easy and cost-effective task, which does not have the above-mentioned limitations. The possibility of using fewer numbers, inexpensive, and long life sensors (because of better working conditions) make these methods very attractive. However, other affecting parameters such as dynamic characteristics of the engine would strongly undermine the robustness and accuracy of these methods.

There are two major methods for modeling the dynamic of the measured vibration signals that are the non-parametric and parametric methods. Non-parametric methods have received most of the attention thus far, and are based upon non-parameterized representations of the vibration energy as a simultaneous function of time and frequency [3]. Discrete FFT [4,5], cyclostationary [6], statistical methods [7], and wavelet [8,9] are some non-parametric methods, utilized to analyze engine vibration signals. On the other hand, parametric methods, based upon parameterized representations of the vibration signal, offer a number of potential advantages [10], such as (i) representation parsimony, as models may be potentially specified by a limited number of parameters; (ii) improved accuracy; (iii) improved resolution; (iv) improved tracking of the system dynamics; (v) flexibility in synthesis (simulation) and prediction, as they are more suitable for both purposes; and (vi) flexibility in fault diagnosis, as they allow for the use of the broad class of parametric diagnosis techniques. There is not any report in which the linear parametric model has been applied for knock detection. It should be mentioned that non-linear ARMA (NARMA) [11,12] and Neural Network [13,14] are two major models used for the vibration signal modeling among the non-linear parametric models. However, these models have several and very complex structures which need enough large data and effort for training in comparing with their linear parametric models such as ARMA.

The proposed method in this paper utilizes the cylinder block vibration signal measured by an accelerometer, and may consequently be classified as the indirect approach. The study introduces an innovative knock detecting method which is accurate even in initial stages of knock with low intensity and also robust to the background noise. This method has two major novelties in comparison with the other indirect approaches. First, the technique of utilizing tachometer signal in parallel with the accelerometer one causes to enhance the procedure accuracy. Second, the vibration signal is represented by a parametric ARMA model to extract appropriate knock indicator feature. Moreover, the knock-sensitive window (KSW) selection method, which is proposed in this research, is also remarkable.

2. Engine knock and theory background

In the following, a brief introduction of the knock phenomenon as well as the background theory of the parametric modeling will be given.

2.1. Engine knock phenomenon

Although the characteristics and mechanism of knock are still not fully understood, its initiation is most widely explained by the self-ignition or auto-ignition theory [15–17]. The auto-ignition theory suggests that as the flame propagates away from the spark plug, the end gas temperature is raised by the heat transfer from the front flame, and more significantly, as a consequence of the compression from the combustion process. If spontaneous ignition of the unburned gas occurs, a rapid pressure rise is produced, which if sufficiently severe, will lead to the characteristic knocking sound. Knock creates high pressure waves in combustion chamber. These powerful waves dissolve cylinder walls lubricant which may cause to piston and cylinder, as well as the piston rings abrasion [1]. Reduction in engine efficiency, increase in air pollution and fuel consumption are some other undesirable side effects of knock.