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Multivariate statistical analysis strategy for multiple misfire detection in internal combustion engines

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ABSTRACT

This paper proposes a multivariate statistical analysis approach to processing the instantaneous engine speed signal for the purpose of locating multiple misfire events in internal combustion engines. The state of each cylinder is described with a characteristic vector extracted from the instantaneous engine speed signal following a three-step procedure. These characteristic vectors are considered as the values of various procedure parameters of an engine cycle. Therefore, determination of occurrence of misfire events and identification of misfiring cylinders can be accomplished by a principal component analysis (PCA) based pattern recognition methodology. The proposed algorithm can be implemented easily in practice because the threshold can be defined adaptively without the information of operating conditions. Besides, the effect of torsional vibration on the engine speed waveform is interpreted as the presence of super powerful cylinder, which is also isolated by the algorithm. The misfiring cylinder and the super powerful cylinder are often adjacent in the firing sequence, thus missing detections and false alarms can be avoided effectively by checking the relationship between the cylinders.

1. Introduction

Inspired by the on-board diagnostic (OBD) regulation, numerous successful approaches have been developed for engine misfire detection and faulty cylinder identification [1–5]. Since the instantaneous engine speed can be measured by the engine control system, the simplest and most cost-effective approach is to evaluate the engine speed fluctuation. This approach has been commonly used in engine mass production [6], but it is still difficult to detect multiple misfire events, especially under critical working conditions (at high speed and low loads).

The misfire event can be detected by evaluating the engine speed waveform, which has been changed due to the lack of positive torque during the expansion stroke of the misfiring cylinder. The features of speed waveform extracted in time-domain [7], frequency-domain [8], or time–frequency-domain [9,10], are effective to identify misfiring cylinders when the engine is running at low-to-middle speed range. However, at high speed, the feature of misfire events may be masked by the following effects: the negligible drop of engine speed due to the misfire event, the low signal-to-noise ratio (SNR) of measured signal and the interference of torsional vibrations [11].

Another popular approach to misfire detection aims to estimate the indicated torque or in-cylinder pressure with a dynamic crankshaft model [12–15]. Although this method provides sufficient information about the engine combustion conditions, it is time-consuming and requires an accurate dynamic model. It would be more efficient to evaluate the

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