A New Approach to Diagnostics of the Combustion Process in Diesel Engines using Vibration Measurements

Part II: Detection of the start of combustion using reconstructed pressure signals

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Part I of this investigation describes the technique of using reconstructed vibration signals to calculate the cylinder pressure in a diesel engine. This approach uses cepstrum techniques and a newly developed windowing technique (that combines Hanning and exponential windows) to reconstruct the pressure signal from vibration measurements. Here, in Part II, this approach is investigated and developed further. The aim in this part is to determine if reconstructed cylinder pressure can be used for detection of the start of the combustion process (SOC) in reciprocating engines. The method customarily used for this type of data capture involves recording of cylinder pressure using pressure transducers mounted on the top of a cylinder head. This method has some obvious disadvantages; it is intrusive, is inappropriate for the more demanding on-board-conditions, and limited lifetime transducers are expensive when used in a harsh environment A simpler and easier method is the one proposed in Part I of this paper i.e., a non-invasive method based on reconstructed pressure signals. The research conducted in connection with Part I demonstrated that reconstructed pressure signals can be used for heat release rate calculations as well as for calculations of the first derivative of cylinder pressure. Furthermore, by using the results obtained, the start of the combustion can be estimated with a reasonable degree of accuracy.

1. INTRODUCTION

Continuing demands for optimal engine performance have led to an increased use of complex engine control systems and closer monitoring of different engine parameters. One of the most versatile engine parameters used for combustion process diagnosis is cylinder pressure. Continuous monitoring of the cylinder pressure signal involves drilling a hole into the engine for the insertion of a sensor; an invasive measure that is not practical for use in the field. A simpler approach is to monitor the acceleration signal on the engine surface and, from the data captured during that monitoring, to reconstruct the pressure signal by using various signal analysis techniques. The approach is not simple and straightforward; the measured acceleration signal is usually contaminated by extraneous noise from sources such as impacting valves, piston slap and combustion in adjacent cylinders. It is therefore necessary to use advanced signal processing techniques[1] to accurately reconstruct the combustion pressure in a single cylinder. There are two different ways to reconstruct the cylinder signature from external measurements: 1) vibration measurement or 2) crankshaft speed measurement. Analysis of and reconstruction of cylinder pressure by vibration-based measurements can be performed with several different techniques, such as inverse filtering,[2-4] time domain[5] and cepstrum analysis.[2,3,6] The crankshaft speed method can also be used to reconstruct the cylinder pressure.[7] In this method, predicted cylinder pressure compared to the instantaneous angular velocity of the crankshaft using a model is based on algorithm techniques and pattern recognition. Yapin compared the methods listed above and concluded that with existing methodology, small changes in the combustion process can easily be detected using vibration-based methodology but not so easily with the crankshaft speed method.[8] Despite this conclusion, the crankshaft speed method does have the potential to reconstruct quite accurately cylinder pressure. This is because the measured response signal has reduced reverberation, reduced dispersitivity, and low noise. However, with current knowledge and technology these advantages are outweighed by the low-cost and simplicity of some vibration-based methods of measurement, such as the methodology described in this paper and in Part I of this paper.

The primary reason for selecting this technique is its accuracy in detecting small changes in the combustion process.[8] Other reasons behind the selection are the simplicity with which measurements can be performed and low cost.

The reconstruction of the pressure signal is not straightforward. Many elements must be factored in during the analysis, in particular, variations in engine structure transfer functions[5] due to the influence of piston slap, impacting valves, and temperature. It well known is that the phase variation of the transfer function must be factored in to obtain a truly accurate reconstruction of cylinder pressure.[9]

In this study, the method of measurement of engine surface vibration reported in Part I is further investigated. It is also used to generate reconstructed cylinder pressure data for calculation of heat release rates (HRR). Data collected and calculated using this method have been validated by comparing the results with the customary direct measurement method, which uses invasive sensors. HRR data and calculations from both methods were compared for further validation of this non-invasive method.

2. MEASUREMENT DETAILS

All investigations were performed at Luleå University of Technology's Engine Laboratory as outlined in Part I of this paper.

A three-factor central composite face design was used for testing the engine under different running conditions and with