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

Part I: Reconstruction of cylinder pressure from vibration measurements

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There is a steadily growing demand for reliable, non-invasive measurement methods which can be used to monitor combustion in diesel engines. An effective, non-invasive method would make it possible for those using diesel engines to economically detect malfunctions during combustion. The main objective of this paper is to show how, through reconstruction, it is possible to generate data on combustion parameters, which can then be used for engine diagnostics. The combustion parameters are the maximum cylinder pressure ($p_{\max}$,) and the derivative of the pressure rise ($dp/d\alpha$). The idea is based on reconstruction by using the transfer function, TF, from the combustion chamber to the engine surface and the measured vibration response signal of the engine surface. The analysis is based on a non-linear method called complex cepstrum and signal processing techniques. The TFs were modified to fit slightly different situations such as other cylinders of the same engine; where use can be made of symmetry. A new approach based on a new tailor-made window for reconstruction of the cylinder pressure is also presented. A matrix with engine TFs for varying speed and load was obtained. The matrix can be used as a data bank of TFs for reconstruction of the cylinder pressure at different operating conditions. An extensive analysis of the cycle-to-cycle variations was carried out, both for the measured and reconstructed cylinder pressure. The main parameters of the cylinder pressure; the maximum cylinder pressure ($p_{\max}$,) and the derivative of the pressure rise ($dp/d\alpha$), are thoroughly examined in order to validate the procedure.

1. INTRODUCTION

The cylinder pressure can provide considerable information about combustion performance. The established method used to monitor the cylinder pressure pulse is to drill and machine a hole in each engine cylinder and insert a high-pressure transducer. This is a very expensive and complicated method that is only suitable for measuring laboratory engine performance. Thus, there is a great need for a cheap and reliable method to measure the pressure pulse from outside the engine body. With the invasive method, cylinder pressure measurements are usually carried out with the pressure transducer mounted flush to the cylinder wall to avoid resonances. The transducer works in a harsh environment, making its life limited. Apart from being expensive, there is also very limited space for mounting transducers on cylinder heads. Thus, there is a need to use alternative methods such as transducers (i.e., accelerometers) attached to the engine surface for reliable and inexpensive measurements of cylinder pressure for performance and condition monitoring.

The engine is a complex structure, and reconstruction of the cylinder pressure for the purposes of engine diagnosis and control is not straightforward. A workable method has to be able to handle wave dispersion, reverberation, and noise in the structure. To use vibration data in the calculation of cylinder pressure, an elaborate and detailed procedure is necessary. To minimise the variability of the TFs, an improved approach for reconstruction of cylinder pressure from vibration measurements is presented in this paper. The method uses a tailor-made filter that is based on a combination of two standard windows: 1) a Hanning window, and 2) an exponential window. This new, tailor-made window is effective in capturing vibration signal data particularly the most interesting part of the signal, which is around top dead centre (see Fig. 3). The signal processing analysis of data collected using the window is based on a non-linear method called complex cepstrum.

The main objective of this paper is to describe how data are interpreted so as to develop combustion parameters, which can then be used for engine diagnostics purposes. The parameters most frequently required for engine condition monitoring are maximum cylinder pressure ($p_{\max}$,) and the derivative of the pressure rise ($dp/d\alpha$). Data concerning these parameters are extensively investigated and a statistical analysis is performed for each cylinder to assess the accuracy and validity of the methods. A matrix with engine TFs at varying speeds and loads is obtained. The matrix is used as a data bank of TFs for reconstruction of the cylinder pressure at different operating conditions.

2. BACKGROUND AND REVIEW

Several researchers have investigated the feasibility of reconstructing cylinder pressure in diesel engines. In this method the transfer functions are manipulated and inverted to assess conditions inside the cylinder. This method is presented in material by Lyon,[1] Azzoni[2] and Randall et al.[3], who describe various aspects of the problem. This section discusses and illustrates phase variability and incomplete cancellation of the poles for engine transfer functions. Comments that describe and discuss shortcomings and difficulties in carrying out reconstruction of cylinder pressure are also included in this part. Methods used to perform reconstruction are also presented.