Analysis of Cylinder Pressure Measurement Accuracy for Internal Combustion Engine Control

Xiaoguo Storm , Heikki J Salminen , Reino Virrankoski and Seppo Niemi
University of Vaasa, Finland
Jari Hyvönen
Wärtsilä Finland Oy, Finland

Abstract

With the tightening requirements on engine emission and performance, pressure based combustion controls are becoming common in medium speed large bore reciprocating internal combustion engines. The accuracy of the cylinder pressure data including the raw pressure value at its corresponding crank angle, has a vital impact on engine controllability. For instance, this work shows that a 1-bar pressure offset leads to a 0.7% variation in the total heat release (THR) while the 50% heat release crank angle (CA50) can be shifted by 2 degrees. Similarly, with a single degree error in the crank position, the indicated mean effective pressure (IMEP) gets a 1.5% error. Thus, in this work the typical errors for cylinder pressure measurement are reviewed and analyzed for large bore four stroke marine and power plant production engines.

The main sources of error for pressure measurement are thermal shock and installation defects. Meanwhile, calibration is carried out for ten production pressure transducers to provide a general accuracy result of the pressure transducers that are used in production engines.

The main sources of error for crank angle position monitoring - when done with a flywheel-based inductive system, manufacturing tolerance, installation, and the relative displacement between the pickups and the shaft due to shaft bending, shaft longitudinal movement, torsional vibration and engine block vibration are the main sources of error.

In this paper, those errors are quantified individually through simulation and their impacts on IMEP and CA50 are also presented. At last, cylinder volume deformation and its impact on combustion diagnostics are also estimated. From the result it is concluded that torsional vibration and cylinder volume deformation have the most significant effects for combustion analysis.

Introduction

The cylinder pressure signal provides a valuable source of information for engine monitoring, diagnostics and control because it is a direct feedback from the combustion status [1] [2]. With the toughening requirements on engine emission and performance, pressure-based combustion control systems have been regarded as the potential gain for the future engine, which relies mostly on pressure-extracted information such as IMEP, heat release rate, combustion duration, compression condition etc. In order to guarantee the precision of the extracted parameters, both the pressure and crank angle need to be measured with a high accuracy.

Cylinder pressure transducers have been used in research for decades, however, since recent years they are widely used in production applications due to the decreasing price of piezoelectric pressure transducers. Piezoelectric pressure transducers have various advantages that make them suitable for production applications, such as long lifetime, high natural frequency, and low price. However, there are some sources of error which impact the pressure measurement accuracy [3]:

- The piezoelectric pressure transducer is sensitive to temperature which can cause thermal shock, signal drift and sensitivity variation.
- The installation of the transducer has an effect on the accuracy of the measurement because of the location and mounting method.

On top of obtaining high accuracy cylinder pressure measurement data, there are higher requirements for a precise crank angle or cylinder volume measurement for thermodynamic analysis. There are two different methods to measure the crank angle: a crank angle encoder and a teethed/slotted wheel. Literature claims that the most accurate method to measure cylinder pressure is to use a crank angle encoder as a trigger source to guarantee that each pressure is measured at a predefined crank angle. Although this solution shows high angular accuracy, it cannot be applied in production because of the practical and price restrictions, and reliability reasons. Thus, wheel-based solutions are commonly used in production applications.

Inductive crank angle measurement is one of the most common solutions for production applications because of its reliability, durability and cost effectiveness. However, in practice, this system always produces considerable deviation from the actual crank angle position caused by mechanical and operating sources [4] [5]:

- The manufacturing tolerance of the flywheel and the number of teeth.
- Installation errors: eccentricity, swash, and sensor air gap variations.
- The relative displacement between the pickups and the shaft due to shaft bending, shaft longitudinal movement, and torsional vibration.
- Inductive sensor vibration caused by the engine block vibration because of the component coupling.
- Other sources of error: electromagnetic interference and time delay.

Except for the above-mentioned main sources of error, pressure pegging and TDC offset determination also contribute to errors in a