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ScienceDirect

Procedia Engineering 177 (2017) 297 – 302

Procedia Engineering

www.elsevier.com/locate/procedia

XXI International Polish-Slovak Conference "Machine Modeling and Simulations 2016"

Analysis of the coefficient of variation for injection pressure in a compression ignition engine

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Abstract

Pressure variability in injection pipes (p_w) supplying fuel to a diesel engine cylinder was analyzed. Pressure levels were recorded at the injector nozzle. To define the variability of pressure, coefficients of variation for the injection pressure (COV_{p_w}) recorded during the operation of the engine were evaluated. The results demonstrated that coefficients of variation COV_{p_w} can be used to find the start of injection. Uncertainties of the results were analyzed. The test results included the data for the mineral or bio-fuel powered engine operating at full load condition within the speed range from 1000 to 2000 rpm.

Peer-review under responsibility of the organizing committee of MMS 2016
Keywords: Engines; injection pressure; coefficient of variation; diesel; bio-fuel;

1. Introduction

Elementary events that occur in a certain order in an operating combustion engine are the source of mechanical disorders. The signals generated by particular parts or units are typically non-stationary. Random interferences in cycle engines cause cycle-to-cycle variations in engine performance even at steady state. In paper [1], the authors analyzed statistical characteristics of the signals generated by the processes taking place in an internal combustion engine, focusing on indicated pressure in combustion chamber and injection pressure. The signals were found to be quasi-periodic and assumed to be stationary and normally distributed. Since their values are used to control and diagnose engine operation, it is necessary to evaluate uncertainties of measurement results. In [2], the authors

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Peer-review under responsibility of the organizing committee of MMS 2016
doi:10.1016/j.proeng.2017.02.228

demonstrated suitability of various signal descriptors for engine performance assessment. One of the descriptors proposed [3] is the coefficient of variation. This paper aims at evaluating feasibility of using this descriptor for fuel injection process.

The way the cylinder is powered with fuel affects the processes of combustion and heat release. The most important fuel supply parameters include the start and duration of injection and injection pressure [4]. Injection start time varies with load, speed and fuel type used. The start of injection (SOI) has an influence on combustion performance. Too early injection start, thus the start of combustion, increases temperature in the combustion chamber and NO_x emission levels and reduces HC emission levels. Late injection start under no load may lead to incomplete combustion and emission of unburnt parts of HC [5]. If the relationship between the real time of injection start and that determined from the characteristic points of recorded plots is known, the effect of injection system parameters on the combustion process can be defined. The moment when the length of fuel spray is 1·mm or when the injector needle lift exceeds 0.04 mm is said to be the real start of injection. This paper describes and analyzes the results obtained from the injector needle lift and injection pressure measurements.

We can assume that the initial displacement of the needle, recorded by induction motion sensors, results from elimination of initial stress and strain of the seat and nozzle needle. The moment this takes place is the start of the so-called dynamic nozzle opening. When the needle is lifted away from the seat, the fuel is allowed to pass from the pressure chamber to the injector sac, which is confirmed by a temporary pressure drop in the pressure chamber. It is evident that the start of the needle lift measured with an induction motion sensor does not determine clearly the so-called dynamic spray opening. It is often assumed that the position of the first local maximum of pressure measured at the injector nozzle corresponds to the moment of dynamic spray opening and the start of fuel injection and needle lift. Experimental studies did not confirm this hypothesis [6]. The same researcher demonstrated that pressure at that point did not correspond to the dynamic pressure of opening. The excess dynamic pressure relative to static pressure results from overcoming friction forces and inertia of the needle [7]. Analysis of the results obtained at the Laboratory of Internal Combustion Engines, Kielce University of Technology [8] indicated high uncertainty of injector needle lift measurements. Therefore the authors of this paper decided to check whether it is possible to determine on the basis of injection pressure plots the interval in which fuel is injected to the combustion chamber. Encouraged by positive results from application of the COV to evaluation of in-cylinder pressure variation [9], the authors adopted this descriptor for analyzing injection pressure signals. The calculation results presented here were obtained with the use of free R statistical software. An important advantage of R software is that it has a number of pre-defined statistical functions that allow fast and easy calculation without a requirement of writing any procedures.

2. Scope of study

The experimental data used in this study were obtained from the tests performed on a Perkins AD3.152 UR three-cylinder combustion ignition engine. Technical data of the engine and a detailed description of four measurement paths used: injection pressure, combustion pressure, needle lift and crank angle (CAD) are included in [8]. A CL31 ZEPWN Marki piezoelectric transducer, mounted at the point at which the injector is linked with the high pressure pipe, provided the fuel pressure signals and the measured pressure is called the injection pressure. The transducer had a resonance frequency of 50 kHz, sensitivity of 126 pC/MPa, measurement range 0 ÷ 100 MPa, non-linearity ≤0.5 % and charge amplifier CL 111. The input resistance of the amplifier was about 10^{13} **Ω**, with non-linearity of ≤0.1% and noise ≤0.2%. The quantities measured were remembered as a function of CAD with a resolution of 1.4º, which allowed the registration of 512 measurement points for each engine working cycle. The measurement results analyzed in this paper were obtained for the engine operating at full load condition at a rotational speed varying from 1000 to 2000 rpm. The fuel used included diesel and fat acid methyl esters (FAME). The values were recorded for all engine operating conditions for 50 full working cycles [8].

3. Example measurement results for injection pressure and injector needle lift

Statistical analysis of the recorded injection pressure values and needle lifts was reported in [10]. Figure 1 shows example results of experimental studies. When the engine was powered with the mineral fuel, the mean value of maximum injection pressure increases with an increase in the crankshaft rotational speed of about 45% in the