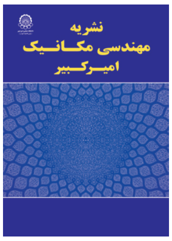

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Defining Start and Duration of Combustion in HCCI Engines using Mean-Value Method for Control Applications

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ABSTRACT: In recent years, homogeneous charge compression ignition engines are a promising idea to reduce emissions and fuel consumption of internal combustion engines. Thus many researchers and industries have focused on this topic. Combustion phasing control is the main problem in the mentioned engines' commercialization. There are some key parameters affecting the combustion characteristics. A single zone thermodynamic model can investigate these effects numerically. In this paper, a single zone thermodynamic model is developed and validated with experimental data. The developed model includes detailed chemical kinetics. This model is used to study the effects of inlet temperature and pressure, equivalence ratio, exhaust gas recirculation rate, inlet air humidity and engine speed on the start of combustion and its duration. The fuel was pure methane and the start of combustion is defined at a crank angle where 5% of the fuel is consumed. As a result, an interpolated relation was introduced to be used in control-oriented models. The third derivation of pressure due to crank angle is either calculated as the most important start of the combustion indicator in control utilization. The results show the proper accuracy of the model and the introduced relations. The effect of inlet air humidity on the start of combustion is negligible.

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1- Introduction

Homogeneous Charge Compression Ignition (HCCI) is a fast heat release mode of combustion based on the auto-ignition of a homogeneous mixture through compression procedure. An HCCI engine can be thought as a hybrid of Spark Ignition (SI) and Compression Ignition (CI) engine, and the HCCI principle incorporates the advantages of both SI and CI engines. The mixture is homogeneous and the combustion temperature is low, which minimizes the Particulate Matter (PM) and Nitrogen Oxides (NOx) emissions. Charge is compression ignited using high compression ratios without throttling losses but with shorter combustion duration which leads to high efficiency. The combination of both high efficiency and low emissions of soot and NOx has made the HCCI engines a promising alternative to traditional engines [1].

Control of ignition timing is the most challenging problem in HCCI engines [2]. Although extended works have been done by researchers to provide control models of HCCI ignition timing, development models to a fast accurate model are steal needs. To provide a model which estimates the Start of Combustion (SOC) accurate in the shortest possible time, knowing the effective parameters and their effective rate on SOC is necessary.

Numerous works on simulating HCCI combustion due to single zone thermodynamic model have been done which show the necessity of it on trading engine performance [3]. For example in the works which were provided by Zhang and et.al [4], Shahbakhti and et.al [5] and Jahanian and Jazayeri [6] this model was used.

In this work, the model which was provided in [6] is developed by adding Exhaust Gas Recirculation (EGR) and Relative Humidity (RH) terms. Considering employing detailed chemical kinetics in the provided model, calculating combustion parameters with kinematical way is possible. Finally, tow correlations to estimate SOC and combustion duration separately due to engine inlet variables are offered to increase the speed of calculations in control approaches after investigating the effect of inlet variables on SOC and combustion duration respectively.

2- Model Description

To employ detailed chemical kinetics, a single zone thermodynamic model which is named Thermo-Kinetic Model (TKM) to trade SOC and HCCI engine performance is developed and used. The fuel of studied engine was pure Methane and simulation is done in MATLAB® commercial software programming environment adding CANTERA open source module.

The TKM includes detailed chemical kinetics of methane oxidation including 325 chemical reactions and 53 species (GRI 3.0 [7]). SOC and combustion duration are defined at a crank angle where 5 and 95 percent of fuel consumed respectively.

3- Model Validation

According to relations which were illustrated in detail at [6], TKM is produced in MATLAB® to simulate closed cycle of HCCI engine. Simulation results are considered by [8] to validation. This consideration is done for Caterpillar 3500 Methane fueled HCCI engine which introduced in Table 1. The results of simulation and experimental data which are adopted from [8] for In-Cylinder pressure, are considered in Fig. 1 to emphasize the TKM accuracy.

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Table 1. Caterpillar 3500 single cylinder engine configuration [8]

Number	Character	Value (unit)
1	Bore × stroke	10×190 (mm)
2	Connecting rod length	350 (mm)
3	Compression ratio	17
4	IVC	20 (aBDC)
5	EVO	40 (bBDC)

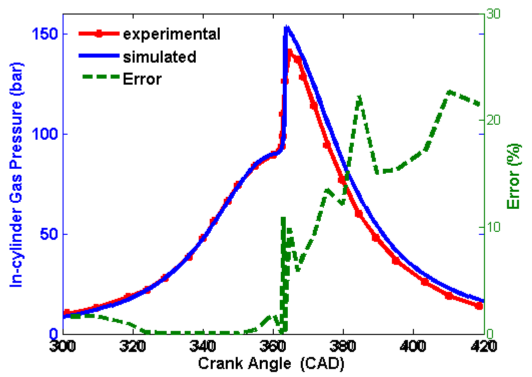

Fig. 1. In-cylinder pressure, Inlet pressure 2 bar [8]

4- Results and Discussion

In this section over than 2400 results of SOC and combustion duration from TKM due to a wide range of engine inlet variables (engine speed, EGR and etc.) changing are analysed. First, considering changing in one variable and stabling the others, the sensitivity of SOC and combustion duration due to that variable, are calculated and shown by a power correlation. In the following, according to the superposition, SOC and combustion duration can be defined by a combination of these correlations and considering a correction factor which is set by best curve fitting to achieve minimum errors. These correlations are shown in Eqs. (1) and (2) for SOC and combustion duration respectively.

$$SOC = 969.28 \frac{N^{0.01892} \varnothing^{0.01283} (1+EGR)^{0.001314}}{P_{IVC}^{0.01921} T_{IVC}^{0.1671}} \quad (1)$$

$$\theta_d = 151.62 \frac{N^{0.7209} (1+EGR)^{0.2729}}{\varnothing^{0.8999} P_{IVC}^{0.6312} T_{IVC}^{1.186}} \quad (2)$$

The accuracy of presented correlations on estimating SOC and combustion duration due to TKM results are reported in Table 2. This table reports that 82.2 percent of 2400 cases of SOC estimating by Eq. (1) have less than 1 CAD variance due to TKM. The acceptable variance for control approaches is less than 2 CAD [5].

Table 2. The accuracy of Eqs. (1) and (2) in prediction of simulation data

Number	Results by	Value (unit)	
		SOC	$\boldsymbol{\theta_d}$
1	E< 1 CAD	82.2 (%)	67.8 (%)
2	E< 2 CAD	89 (%)	88.9 (%)
3	E<3 CAD	94 (%)	98.3 (%)

5- Conclusions

- Developed TKM is suitable to predict SOC and includes a wide range of engine inlet variables such as engine speed, EGR and RH.
- Provided correlation to estimate SOC has enough accuracy for control approaches.

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