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Accommodation Closed-loop Control of Dieseline Fueled Flexible Fuel Engine Based on In-cylinder Pressure Sensor

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Abstract: This paper conducts investigation on accommodation closed-loop control of dieseline fueled flexible fuel engine. In our previous work, gasoline/diesel blend ratio estimation method was proposed and acted as a feedforward controller. In this paper, power performance closed-loop control systems with or without blend ratio estimation model are simulated respectively at constant and variable load to demonstrate the necessity of feedforward controller to control system. Results show that, whether at constant or variable load, power indicators of the system with feedforward controller track the target value well. However, for system without feedforward controller, power performance deteriorates obviously, especially in variable load condition. Besides, accommodation closed-loop control system for dieseline fueled flexible fuel engine is established. The algorithm is executed by adjusting the main injection timing to seek the most economy point on the premise that the power performance of the engine can be ensured simultaneously. Compared with open-loop control algorithm, closed-loop control system is less sensitive to fuel estimation model error, which proves to be of better consistency. Moreover, the practical output torque follows the target value well and the indicated efficiency can also be optimized.

Keywords: in-cylinder pressure sensor; closed-loop combustion control; dieseline; flexible fuel engine; accommodation control; economy optimization; PPCI;

1. BACKGROUND

PPCI is considered to be one of the most promising combustion concepts. It has been widely studied by Reitz (Hanson, R., Splitter, D. and Reitz, 2009, Ra, Y. *et al*, 2011), Yang F *et al* (Yang, F. *et al*, 2013), and Sellnau *et al* (Sellnau *et al,* 2015) and has been proved more easily to realize and control than HCCI. However, with further investigations, there are several difficulties in PPCI realization. Combustion phase control is still the main obstacle of gasoline PPCI realization. Meanwhile, for diesel PPCI, it's hard for diesel to generate homogenous charge because of its poor vaporability. Besides, the operating range of PPCI is limited. It has been suggested that fuel with low octane number and good vaporability is ideal for PPCI combustion. Researches conducted by Manente *et al* (Manente, V. *et al*, 2009, 2010), Adhikary *et al* (Adhikary *et al*, 2012), Chang *et al* (Chang *et al*, 2012), B. Wang *et al* (B. Wang *et al*, 2014), and Ciatti *et al* (Ciatti, S., and Subramanian, S. N., 2011) focused on PPCI combustion fueled with low octane number fuels.

Research is conducted by Zhong *et al* (Zhong *et al*, 2005) who focuses on designing fuel characters through blending gasoline together with diesel, and the blended fuel has been called "dieseline" firstly by Xu's group (Rezaei, S. Z. *et al*, 2011 and Zhang, F. *et al*, 2013). Adam Weall *et al* (Weall, A., and Collings, N., 2007), Kalghatgi (Kalghatgi, G. T., 2005) and Shi *et al* (Shi, Y., and Reitz, R. D., 2010) conducted research on "dieseline" as well and found it of good auto-ignition and evaporation property. It is generally accepted that fuel with characters between diesel and gasoline is more suitable for PPCI combustion. Moreover, diesel and gasoline are two of the most widely used fuels around the world and can be easily purchased in commercial market. Nowadays, refineries around the world have been equipped with complete refining facilities. Hence, "dieseline" could be a good alternative before a more suitable fuel for PPCI combustion is widely supplied. In this study, diesel and gasoline blended fuel is applied, whereas the control algorithm raised in this paper lays foundation for PPCI combustion control fueled with any fuel.

FFE (flexible fuel engine) is regarded as a frontier and hot topic of internal combustion engine research. Researches show that some alternative fuels can not only optimize the in-cylinder combustion process of traditional gasoline and diesel engine, but also can reduce the emission. FFE combined with PPCI provides a feasible solution to meeting the ever strict emission regulation.

However, the control algorithm of the traditional diesel engine is designed mainly based on open-loop control. The relationship between control parameters and performance indicators (such as power, economy, emission and so on) is established qualitatively based on experience or experiment. Then, the control parameters can be optimized and determined by a great quantity of experimental calibration. Therefore, the alternative fuels (such as dieseline) could bring new problems to the original engine control system because of their different physical and chemical characters.

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There are two major problems for dieseline fueled FFE to overcome. The first problem is the output torque varies with dieseline of different diesel volumetric ratios. As shown in Fig. 1 (Wang, J., Yang, F., and Ouyang, M., 2015). The CFM (cycle fuel mass) is determined by MAP based on open-loop control. The output torque demand of the whole powertrain could be obtained through MAP according to the driver's speed demand and pedal position. Then, the torque demand will be interpreted into CFM. However, the practical output torque will be different under the same load demand for dieseline of different diesel volumetric ratios because of their different lower heating values. As a result, the engine power performance cannot keep constant when using different fuels. Similarly, improper main injection timing will bring the possibility of efficiency deterioration or even misfire.

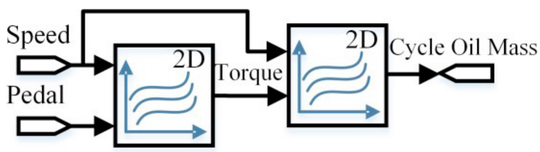

Fig. 1. CFM open-loop control.

Former researches which were conducted respectively by Snyder *et al* (Snyder *et al*, 2010), Zhao J *et al* (Zhao, J., and Wang, J., 2012), Mirheidari S *et al* (Mirheidari S *et al*, 2010), and Wang J *et al* (Wang, J., Neely, G. D., and Ryan, T. W., 2006) on diesel and bio-diesel blends fueled engine accommodation control tried to solve this problem mainly based on open-loop control algorithm through blend ratio estimation. The estimated blend ratio can be another dimension of MAP in engine electric control system. Thus, the control parameters are not only determined by driver's demand, but also by blend ratio. However, to precisely meet the demand of output torque and economy, the blend ratio estimation model should be very accurate, which could be difficult to realize and bring much more calibration effort.

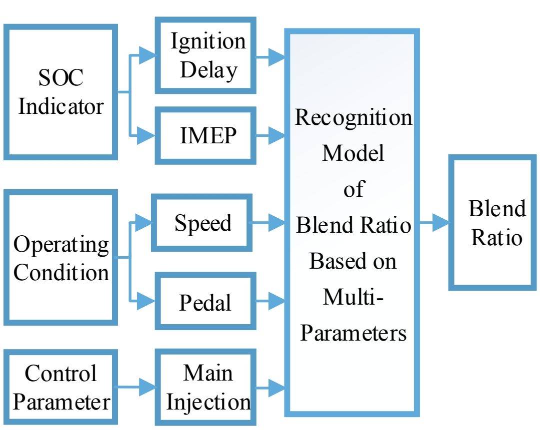

Fig. 2. Multi-indicator fusion blend ratio estimation model.

The research group in Tsinghua University developed closed-loop control algorithm, which was based on blend ratio online estimation. In the former study, the authors adapted multi-indicator fusion blend ratio estimation method to generate different combustion indicators together for better accuracy. As shown in Fig. 2 (Wang, J., Yang, F. and Ouyang, M., 2015). The model is built based on statistical machine learning algorithm in ASCOMO. The inputs of the model are available from the control system. Of all the inputs, pedal and speed refer to operating condition, injection timing is one of the most important control parameters, IMEP and ignition delay are combustion indicators. Blend ratio is the output. Besides, power closed-loop control system and economy optimization method are proposed separately in this study.

Firstly, this paper will discuss the necessity of fuel estimation model based feedforward controller to the control system. Next, a dieseline fueled flexible fuel engine accommodation closed-loop control algorithm is proposed aimed at optimizing power and economy performance simultaneously. Finally, this closed-loop control algorithm will be verified by simulation and the performance indicators of the system will be compared with that of the open-loop control algorithm.

2. EXPENRIMENTAL SETUP

2.1 Fuel

Specifications of Beijing standard RON93 (research octane number) gasoline and 0# diesel are listed in Table 1 and Table 2 respectively.

Table 1. Specifications of experimental gasoline

Parameter	Value
RON	93
Sulphur (m/m)	0.001%
Aromatics (V/V)	35.5%
10% evaporation temperature (ºC)	59.7
50% evaporation temperature (ºC)	107.3
90% evaporation temperature (ºC)	160.2
Density @20ºC (kg/m^3)	755.4
LHV (lower heating value) (J/ mm^3)	32.86

Table 2. Specifications of experimental diesel

Parameter	Value
CN	52.6
Sulphur (m/m)	0.001%
Aromatics (V/V)	29.6%
10% evaporation temperature (ºC)	214.8
50% evaporation temperature (ºC)	266. 1
90% evaporation temperature (ºC)	333. 6
Density @20ºC (kg/m^3)	839.3
LHV (lower heating value) (J/ mm^3)	36.01

Blend ratio (BR) is defined as the volumetric ratio of diesel in the blended fuel, as shown in (1). The footnote "D" means diesel while "G" refers to gasoline. *V* is the volume of fuel. In