Available online at www.sciencedirect.com
ScienceDirect
IFAC PapersOnline CONFERENCE PAPER ARCHIVE
IFAC-PapersOnLine 49-11 (2016) 020–027

Composite Control of DOC-out Temperature for DPF regeneration

Jinbiao Ning * **Fengjun Yan** **

* *McMaster University, Hamilton, ON, Canada. (e-mail: ningj4@mcmaster.ca).*
** *McMaster University, Hamilton, ON, Canada. (e-mail: yanfeng@mcmaster.ca)*

Abstract: Control of Diesel Oxidation Catalyst (DOC) outlet temperature is critical for the downstream Diesel Particulate Filter (DPF) regeneration. However, the disturbances, delay time variation and model uncertainties make it difficult to control DOC outlet temperature. A Composite Controller (CC) based on modified Active Disturbance Rejection Control (mADRC) with delay-time adaptation was proposed for DOC-out temperature control in this paper. The proposed controller includes a model-based Feedforward controller(FF) and a mADRC. The model based FF was designed based on the model between the reference temperature, inlet temperature, mass flow rate and the fuel injection. The mADRC was modified from regular Active Disturbance Rejection Contoller (rADRC) with an adaptation of input delay time. The input delay time is adapted according to the mass flow rate of exhaust gas. Simulation and test results through high-fidelity GT-Power model show that the proposed design can effectively control the DOC-out temperature.

Keywords: Diesel Oxidation Catalyst, DPF regeneration, Active Disturbance Rejection Control, Post Injection, Composite Control.

1. INTRODUCTION

The advanced Diesel after-treatment system consists of DOC, DPF and SCR (Selective Catalytic Reduction), as can be seen in Fig. 1. The PM emission is accumulated and burned in the DPF, which is called DPF regeneration. The use of DPF is considered to be the only feasible Diesel after-treatment technology that can meet the increasingly stringent PM regulations (Guan, B. et al. (2015)).

Passive regeneration and active regeneration are two different ways for DPF regeneration. Since passive regeneration is limited and not enough to keep the filter clean in long-term, the active regeneration of DPF is necessary (Johnson, T. et al. (2008)). The active regeneration of DPF divides into two stages (Kim, Y. W. et al. (2014)): 1) close post injection is used to drive the DOC temperature up to light-off temperature for high hydrocarbons (HC) conversion efficiency. 2) far post injection in cylinder or downstream injection in the exhaust pipe is adopted to boost the DOC outlet temperature to satisfy the regeneration temperature.

The DOC-out temperature is critical for DPF periodical regeneration that DPF inlet temperature should be high enough to effectively burn the accumulated soot in the DPF and should be kept below a certain threshold to prevent damage to the DPF. The control of DOC-out temperature is challenging due to several factors including wide-range engine operations, DOC thermal inertia, the complexities of the reactions in DOC, and the physical saturation of the fuel injectors.

Several control strategies (Bencherif, K. et al. (2009); Lepreux et al. (2012); Kim, Y. W. et al. (2014)) were proposed to address this issue. Linear Parameters Varying (LPV) controller was demonstrated in (Bencherif, K. et al. (2009)) to have better tracking performance for the Diesel Particulate Filter Thermal Management by comparing with model-based PID controller. Model-based temperature control with parameter adaptation by exhaust gas velocity is proposed in (Lepreux et al. (2012)). Model Predictive Control was proposed in (Kim, Y. W. et al. (2014)) for DOC-out temperature control during DPF regeneration and achieved small temperature error in general but more overshoots than the production controller. However, the above controllers still have nontrivial overshoots that are harmful for the DPF regeneration. Therefore, more efforts are required to get better tracking performance of the DOC-out temperature for better DPF regeneration.

In this paper, a novel Composite Control (CC) based on modified Active Disturbance Rejection Control with delay-time adaptation is proposed for the DOC-out temperature control. The Active Disturbance Rejection Control (ADRC) concept (Gao Z et al. (2001); Han J (2009); Gao Z (2006)) has been widely used in many fields to deal with disturbances and model uncertainties (Zheng Q et al. (2009); Gao Z (2003); Jinbiao Ning et al. (2014))..

The main contributions of this paper are: 1) The DOC-out temperature model is identified as a process model with variable delay time and rewritten in state space form. 2) The Composite Control based on modified Active Disturbance Rejection Control is proposed for DOC-out temperature control. 3) The Feedforward controller is achieved

10.1016/j.ifacol.2016.08.004

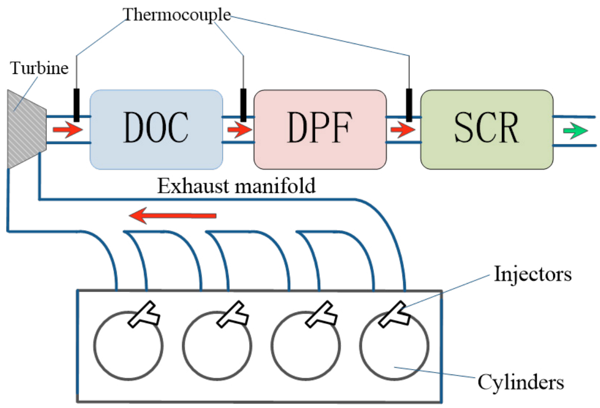

Fig. 1. Aftertreatment system configuration

based on the the relation among the inlet temperature, the mass flow rate of inlet exhaust gas and the fuel injection. 4) The relation between the delay time and mass flow rate is fitted based on the data from high-fidelity DOC model and used for the delay-time adaptation.

The rest of the paper is organized as follows. A brief introduction of control problem and DOC thermal dynamics is demonstrated in section II. The design of Composite Control based on modified Active Disturbance Rejection Control with delay-time adaptation is presented in section III. Simulation results based on 1-D high-fidelity DOC model are introduced to verify the proposed approach in section IV. At the end of the paper, conclusion is given.

2. THE CONTROL PROBLEM AND MODELING OF DOC

As mentioned in Section 1, DPF active regeneration consists of two stages. The first stage is out of the scope of this paper. The second stage is achieved by bringing the DOC-out temperature up to about $650°C$ by far post injections in cylinder or downstream injections in the exhaust pipe after the temperature condition satisfies the requirement of first process. To understand the control problem and the dynamics of the DOC system, this section describes the control problem, the principle of DOC system, and modeling of DOC.

2.1 Control Problem

The DOC is a single input single output system (see Fig. 2) with disturbances (DOC inlet temperature T_{in} and mass flow rate of inlet exhaust gas $\dot{m}_{ex}$), input saturation ($0 < U_{inj} < U_{max}$). The output (T) of the system is the DOC-out temperature and the temperature sensor may have measurement noise. The actuator of the control input is a Diesel injector, which has input saturation, i.e. the injector can only inject a greater than zero and lower than an upper bound amount of diesel fuel. The control of DOC-out temperature is asymmetric due to the input saturation, which means that the DOC can be heated up by adding fuel injections but only can be cooled by the natural cooling. There exist disturbances due to different engine operations and model uncertainties including time delay uncertainties due to the complexity of thermal dynamic and chemical reactions.

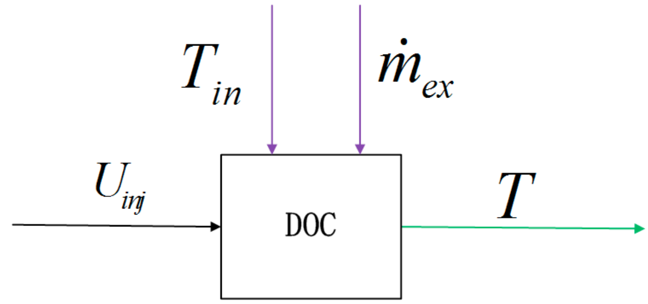

Fig. 2. The control system of DOC including input (U_{inj}), output (T) and disturbances (T_{in} and $\dot{m}_{ex}$)

2.2 The Principle of DOC

The DOC is composed of inner layer (substrate layer) and outer layer, as can be seen in Fig. 3. The substrate layer divides into the washcoat and the substrate wall. The exhaust gas goes through the substrate and oxidation reactions occur on the substrate. The thermal dynamic of DOC is very complicated since it has thermal conduction, convection and chemical reactions.

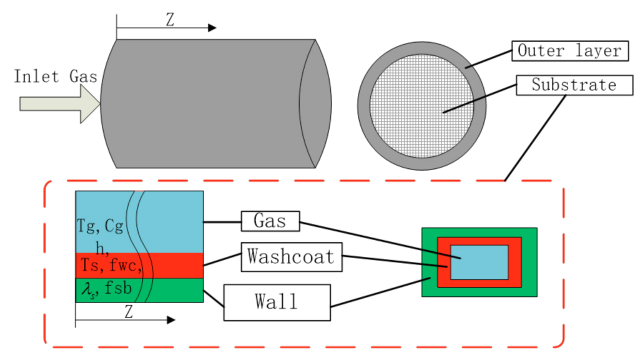

Fig. 3. Schematic diagram of DOC

The chemical reactions in DOC are very complex and more details can be seen in (Sampara, C. S., Bissett, E. J., & Chmielewski, M. (2008); Sampara, C. S., Bissett, E. J., & Assanis, D. (2008); Wang, T. J. et al. (2008); Voltz, S. E. et al. (1973); Song, X. et al. (2013)). The main reactions in DOC include oxidation reactions (Sampara, C. S., Bissett, E. J., & Chmielewski, M. (2008)) and Hydrocarbon storage (Sampara, C. S., Bissett, E. J., & Assanis, D. (2008)), as demonstrated in table 1.

Table 1. Main Reactions in DOC

Oxidation Reactions	
1	$CO + 0.5O_2 \rightarrow CO_2$
2	$C_3H_6 + 4.5O_2 \rightarrow 3CO_2 + 3H_2O$
3	$H_2 + 0.5O_2 \rightarrow H_2O$
4	$NO + 0.5O_2 \rightarrow NO_2$
5	$DF_1 + 19.4O_2 \rightarrow 13.5CO_2 + 11.8H_2O$
6	$DF_2 + 19.4O_2 \rightarrow 13.5CO_2 + 11.8H_2O$
Hydrocarbon Storage Reactions	
7	$Z + DF_1 \rightarrow ZDF_1$
8	$ZDF_1 \rightarrow Z + DF_1$