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Vehicle application of model-based catalyst control ☆

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Abstract

Standard stoichiometric control of a three-way catalytic converter is often not sufficient to meet new, very stringent, emission standards. This paper presents vehicle based testing of a model-based controller that takes into account dynamics of the catalytic converter. By applying such a controller higher efficiency of the catalytic converter under dynamic operation is achieved, which ultimately leads to lower emissions and a possibility to reduce the cost of the system.

Keywords: Automotive emissions; Control-oriented models; Model-based control; Nonlinear systems; Observers

1. Introduction

Three-way catalytic converters have been in use in SI engine vehicles for more then 25 years now and the obtained reductions in CO, HC and NO_x emissions are already very high. The majority of the emissions that occur after converter light-off stem from engine transients caused as a result of the action of typical engine air/fuel controllers, which do not take into account the dynamics of the catalytic converter.

A typical controller uses only a lambda sensor (HEGO—relay type or UEGO—wide range) in front of the catalytic converter to provide a feedback signal to the engine controller. This layout can be considered to provide pure open loop control of the catalytic converter. Moreover, it is typically a static scheme since the desired engine lambda is fixed and set to stoichiometry. More advanced control schemes have been employed in recent years that utilize a second lambda sensor behind or mid position in the catalytic converter. This secondary sensor gives the controller information about the state of the exhaust leaving the catalytic converter with which appropriate action can be taken. This typically means that a rich downstream exhaust mixture leads to a leaner air/fuel setpoint, while a lean mixture leads to a richer air/fuel setpoint. Though an improvement with respect to a pure stoichiometric controller this is still not the most optimal control of the converter as the controller always 'lags' behind emissions performance. In other words, further improvements in preventing emissions can be achieved by anticipating the control requirements for the catalyst and making the appropriate adjustments.

It is well known that an improved system performance can be achieved by controlling the level of oxygen in catalyst, which is stored on the ceria. Ceria stores surplus oxygen during lean transitions while releasing it for oxidation of CO and HC during oxygen deficient (rich) periods. On the other hand NO reduction benefits from the oxygen storage process since more free catalytic sites are available for NO dissociation and more reductants (CO, HC) are free to react during the

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Nomenclature

Notation

A/F	air/fuel ratio (dimensionless)
A, C	system and output matrices
C_x	molar fraction of component x (dimensionless)
f, g	storage and release functions
G	transfer function
K	gain (dimensionless)
k_d	relative oxygen storage capacity (s)
M	molar mass (kg/mol)
$\dot{m}$	mass flow (kg/s)
$\dot{n}$	molar flow (mol/s)
OSC	oxygen storage capacity (mol)
P	state estimate variance
$Q,\ R$	state and measurement noise variance
T	temperature (K)
T_d	time delay (s)
Ts	sampling time (s)
$\mathscr{C}(\mathbf{x})$	accessibility distribution
$d\mathcal{O}(\mathbf{x})$	observability codistribution

Greek symbols

λ	relative air/fuel ratio (dimensionless)
τ	time constant (s)
ζ	relative oxygen storage level (dimensionless)

Subscripts and abbreviations

a	air
c	catalyst
ct	controller
e	engine
est	estimation
ex	excess
exh	exhaust
f	fuel
in	inlet
k	current sample
L	lean
m	measurement
NM	noble metal
o	observer
OSC	oxygen storage capacity
out	outlet
ox	oxidant
P	process
$prod$	reaction product
R	rich
red	reductant
ref	reference signal

process (Balenović, 2002; Harmsen, Hoebink, & Schouten, 2001). The above considerations lead to a standard rule of thumb that the oxygen storage capacity should be kept approximately half filled to promote conversion of all species during sudden transients (lean/rich excursions). This assumption was used in the pioneering work of (Shafai, Roduner, & Geering, 1996). With development of applied on-line models (Balenović, Backx, & Hoebink, 2001; Brandt, Wang, & Grizzle, 2000; Peyton Jones, Jackson, Roberts, & Bernard, 2000) it has become possible to control the oxygen storage level even more accurately allowing even tighter emission control (Balenović, de Bie, & Backx, 2002; Fiengo, Cook, & Grizzle, 2002).

This paper presents experimental verification of the model-based oxygen storage controller. The main aim is to investigate any advantages demonstrated by this method of catalyst control with respect to a standard existing air/fuel controller, without making any change to the existing exhaust layout (components and sensors).

The engine used is a Jaguar 3.0l V6 that employs a close coupled two-brick catalytic converter in the exhaust of each bank. Fig. 1 shows the outline of the applied exhaust system. Since the engine is a V6 each engine bank has it's own exhaust pipe with a two-brick catalytic converter. Sensors are placed in a standard fashion (pre-catalyst UEGO and HEGO between the bricks). This is already problematic from a control perspective since the second brick behaviour cannot be observed. Therefore only the first brick is actually in closed loop control, which naturally involves some adaptation of the control strategy.

The main issue with the system in its standard form is a variability in tailpipe NO_x emission during driver transients. Although not a concern for Californian

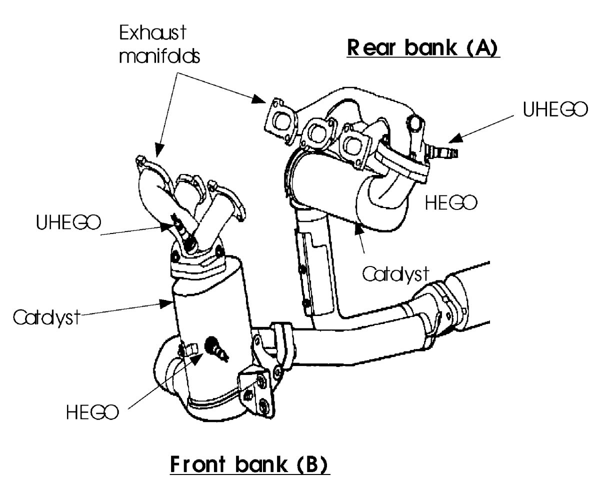

Fig. 1. Applied exhaust system.