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Data-Driven Near-Optimal On-Line Control for an Electrically Heated Catalyst-Equipped Gasoline Engine

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Abstract

An integrated electrically heated catalyst (EHC) in the three-way catalyst (TWC) of a gasoline internal combustion engine (ICE) is a promising technology to reduce engine cold-start pollutant emissions. Pre-heating the TWC ensures earlier catalyst light-off of a significant portion of the TWC. In such a case, the engine could readily be operated in a fuel-optimal manner since the engine cold-start emission is efficiently treated by the warmed-up EHC-equipped TWC. Pre-heating the EHC is an effective way to reduce cold-start emissions, among other possible EHC strategies. However, it might not always be possible to use pre-heating if the engine-start time is uncertain. In such a case, pre-heating can be started when the engine start is known with greater confidence and post-heating the catalyst could be followed. It would then be natural to turn off the EHC when the payoff for the electrical energy spent is no longer effective in engine cold-start emission reduction. The point in time at which to stop the EHC thus needs to be controlled. A model-free on-line adaptive controller aimed at minimizing the total equivalent emission is proposed, which is based on a set of pre-computed look-up optimum EHC stop times for the various possible fuel consumption trajectories. Compared to the theoretically optimal controller, the proposed controller gives a penalty of about 1% emission-based cost. A simulation framework for cold-start control and equivalent emission metric developed earlier are used in conjunction with a validation proposal to compare the performance of the candidate controllers.

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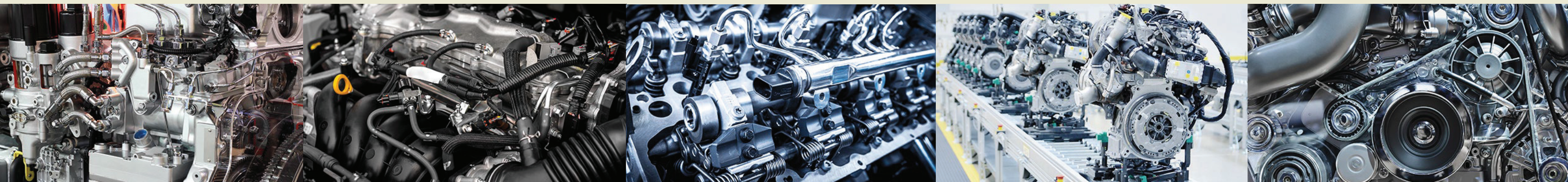

Abbreviations

CO - Carbon monoxide
EATS - Exhaust aftertreatment system
EHC - Electrically heated catalyst
FTP75 - Federal Test Procedure cycle
HC - Hydrocarbons
HPCS - High-power cold-start
ICE - Internal combustion engine
LTI - Linear time invariant
MPC - Model predictive control
MXH - Mixed heating
NEDC - New European Driving Cycle
NOx - Oxides of nitrogen
PRH - Pre-heating
PSH - Post-heating
TWC - Three-way catalyst
WLTC - Worldwide harmonized Light vehicles Test Cycle
bsfc - Brake-specific fuel consumption
$\mathbf{bsfc_{max}}$ - Worst bsfc from the engine map
$\mathbf{bsfc_{min}}$ - Best bsfc from the engine map
C^S - Averaged cost for a controller candidate “S” from among the optimal (O), fixed time (F), look-ahead (D), and adaptive (A) controllers
$J_{\mathrm{Cyc}}^{t_{\mathrm{PRH}}}$ - Total equivalent emission over the cycle (Cyc) with pre-heating duration (t_{PRH})
$m_{\mathrm{s,total,Cyc}}^{\mathrm{EHC\,off}}$ - Exhaust emission mass of species “s” with EHC off for the drive cycle (Cyc)
M_{f} - Fixed upper threshold of fuel consumption used for comparison
$m_{\mathrm{f,eq}}$ - Equivalent fuel mass
$m_{\mathrm{f}}(i)$ - Cumulative sum of fuel consumed at discrete time i from engine start
$m_{\mathrm{f,total}}$ - Total mass of fuel consumed over the cycle
$\bar{m}_{\mathrm{f}}^{m1}$ - Time-series array of cumulative fuel mass for drive cycle $m1$
$m_{\mathrm{s,eq}}$ - Equivalent exhaust emission mass
$m_{\mathrm{s,tp}}$ - Tailpipe exhaust tailpipe emission mass of species “s”
$m_{\mathrm{s,eq}}^{t_{\mathrm{PRH}},t_{\mathrm{PSH}}}$ - Exhaust emission mass of species “s” with pre-heating duration t_{PRH} and post-heating duration t_{PSH}
mx^* - Matched training drive cycle
P_{el} - Electrical power consumed by the EHC
s - Emission species (CO, HC, or NOx)
t_{PSH}^{A*} - On-line adaptive post-heating duration
t_{PSH}^{D*} - Look-ahead post-heating duration
t_{end} - Drive cycle end time
t_{PSH}^{F*} - Fixed controller post-heating duration
t_{PRH} - EHC pre-heating duration
t_{PSH} - EHC post-heating duration
t_{PSH}^{O*} - Optimal post-heating duration
t_{PSH}^{X*} - Set of pre-computed optimal EHC post-heating time
v^d - Validation cycles (v) generated prefixed with different start-idle durations (d)
wt^d - Idle duration weight

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