ABSTRACT

REACTION-BASED MODELING AND CONTROL OF AN ELECTRICALLY BOOSTED DIESEL ENGINE

By

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This dissertation presents the reaction-based modeling of diesel combustion and model-based control of diesel engine air charge system.

This dissertation first presents a control-oriented reaction-based diesel combustion model that predicts the time-based rate of combustion, in-cylinder gas temperature and pressure over one engine cycle. The model, based on the assumption of a homogeneous thermodynamic combustion process, utilizes a two-step chemical reaction mechanism that consists of six species: diesel fuel (C\text{10.8}H\text{18.7}), oxygen (O\text{2}), carbon dioxide (CO\text{2}), water (H\text{2}O), nitrogen (N\text{2}), and carbon monoxide (CO). The temperature variation rate is calculated based on the rate of change of species concentrations; and the heat loss correlation is also used to study the model performance. The accuracy of the model is evaluated using the test data from a production 6.6 L, 8-cylinder, turbocharged engine. The model calibrations are optimized over the entire range of engine speed and load as well as different injection timings and exhaust gas recirculation (EGR) rates. The calibrated reaction-based model accurately predicts the indicated mean effective pressure, while keeping the errors of in-cylinder pressure and temperature small. Especially, the reaction-based combustion model significantly reduces the calibration effort, comparing to Wiebe-based combustion models, when the engine is operated under multiple fuel injections. The calibrated model parameters have a strong correlation to engine speed, load and injection timings, and as a result, a universal parameter calibration structure is proposed for entire operational conditions.

The second part of the dissertation is to obtain a parametric understanding of diesel combustion by developing a physics-based model that is able to predict the combustion metrics, such as in-cylinder pressure, burn rate, and indicated mean effective pressure (IMEP) accurately, over a wide range of operating conditions, especially under multiple injections. In the proposed model, it is assumed that engine cylinder is divided into three zones: a fuel zone, a reaction zone, and an
unmixed zone. The formulation of reaction and unmixed zones is based on the reaction-based modeling methodology, where the interaction between them is governed by Fick's law of diffusion. The fuel zone is formulated as a virtual zone, which only accounts for mass and heat transfer associated with fuel injection and evaporation. The model is validated using test data under different speed and load conditions, with multiple injections and EGR. It is shown that the multi-zone model out-performed the single-zone model in in-cylinder pressure prediction and calibration effort with a mild penalty in computational time.

The third part of the dissertation is modeling and control of engine air path with an electrically assisted boosting system. A physics-based control-oriented engine air path model with electrical assistance has been developed. The model is validated with steady-state engine test data and standard driving cycle data. Through one-dimensional simulation, it is found that the electrically assisted boosting system can improve engine performance under both steady-state and transient conditions. A model-based controller has been developed for the electrical booster (eBoost) and bypass valve to improve the transient performance of engine load response. Experiments have been performed on a Ford 6.7 L, 8-cylinder, turbocharged diesel engine equipped with a prototype eBoost and a standard EGR valve as bypass. Steady-state test results have shown that eBoost is capable of improving engine efficiency by reducing pumping loss, due to lower turbine speed when eBoost is providing additional boost energy.