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Predictive Simulation and Experimental Validation of Phenomenological Combustion and Pollutant Models for Medium-Speed Common Rail Diesel Engines at Varying Inlet Conditions

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Abstract: As internal combustion engines are becoming ever more complex, there is increasing need for engine parameter optimization through simulation, to avoid numerous timely and costly test-bed measurements. When performing simulations for engine performance and emission optimization, the capability of the combustion model used to accurately predict NOx emission formation as well as heat release rates at varying engine conditions becomes increasingly important. Considering the trade-off between computational cost and accuracy of predictions of diesel engine combustion and pollutant models, phenomenological models have a clear advantage compared to their CFD and simple mathematical approximation alternatives. The detailed phenomenological model used in this study is able to capture changes in fuel injection system and charge-air thermal and chemical properties for direct injection diesel motors, while being computationally efficient. This paper aims to show the ability of these models to predict diesel combustion and emission formation during significantly varying inlet charge and injection conditions, in Common Rail medium-speed Diesel engines.

Initially the phenomenological models are calibrated using measurement data from a production Common Rail medium-speed Waertsilae 6L20CR Diesel engine, employing a state-of-the-art turbocharging system. The model calibration includes data from experiments where injection timing and pressure as well as engine load were varied, to determine their influence on combustion and NOx emissions.

The models are then used to predict the heat release rate and NOx formation when the inlet valve timing is changed to earlier Miller timing and the charge air pressure is raised using two-stage turbocharging. Additionally, the models are embedded in a 1-D simulation model of the engine to predict the resulting engine performance. The simulation results are compared with experimental results obtained from the test engine with matching hardware changes, giving an indication of the models' ability to capture the most important combustion and emission formation characteristics.

Results from the study show very good performance of the combustion and emission models, when used to perform operating map-wide simulations with varying fuel injection conditions. When the models are used to predict heat release rate in the two-stage turbocharged engine with Miller timing, the combustion rate is predicted well, with small discrepancies in ignition delay calculation. The emission model correctly forecasts the reduction in NOx emissions as a result of the advanced Miller valve timing, but underestimates the true level of NOx produced.

Overall, the combustion and emission models show good performance, and their short calculation time allows them to be used for multi-variable engine optimization within the calibration ranges. With improvements in the ignition delay and NOx calculation, the models can additionally be used for preliminary engine concept design studies and turbocharger matching through simulation.

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