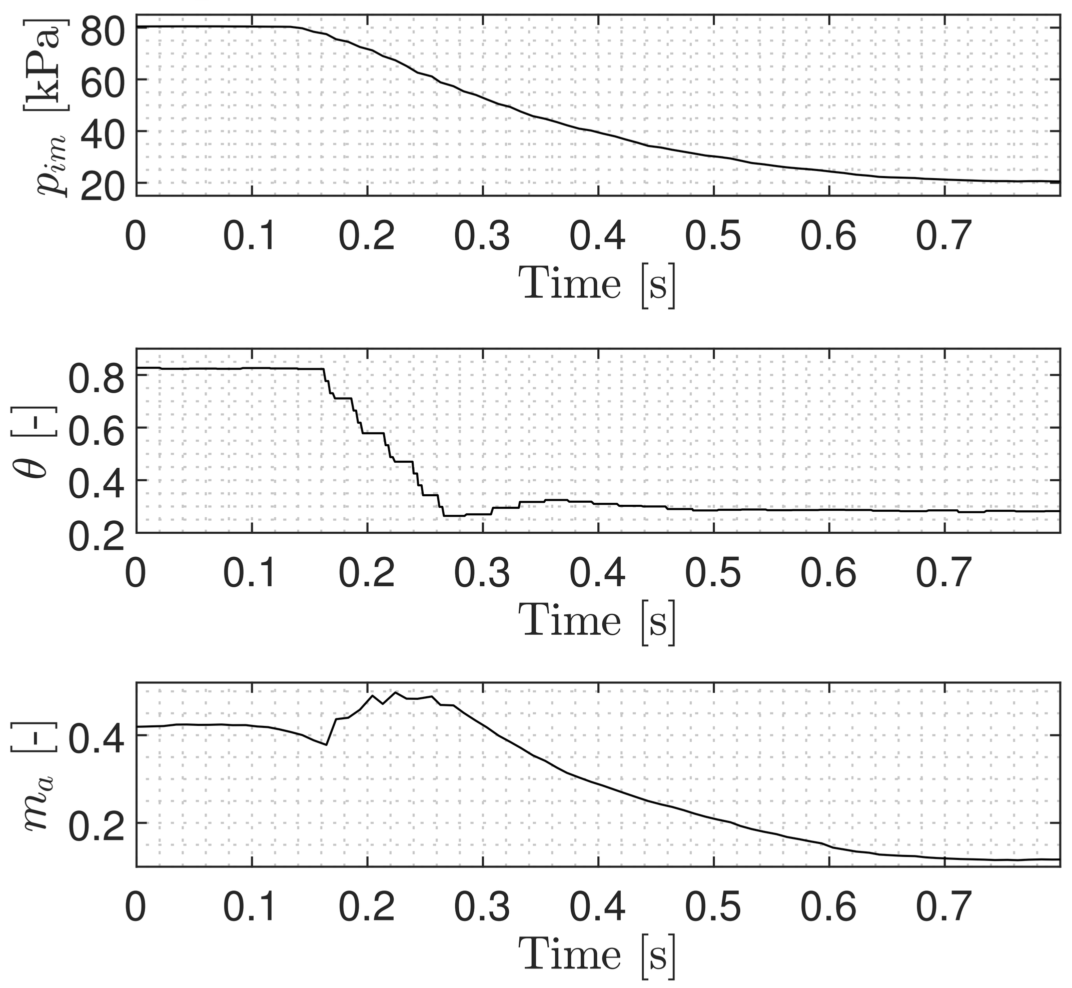
Modeling and Model-based Control of Automotive Air Paths

Robin Holmbom

The strive towards cleaner and more efficient combustion engines, driven by legislation and cost, introduces new configurations, as exhaust gas recirculation, turbocharging, and variable valve timing, to name a few. Beside all the positive effects on the emissions and fuel consumption. They all affect the air-charge system, which increases the cross-couplings within the air-path control, making it an even more complex system to control. As the SI engine uses a three-way catalytic converter, which enforces a condition of stoichiometric combustion, the amount of air flow and fuel flow are connected. This means that the air flow has a direct impact on the driveability of the engine, through the torque.



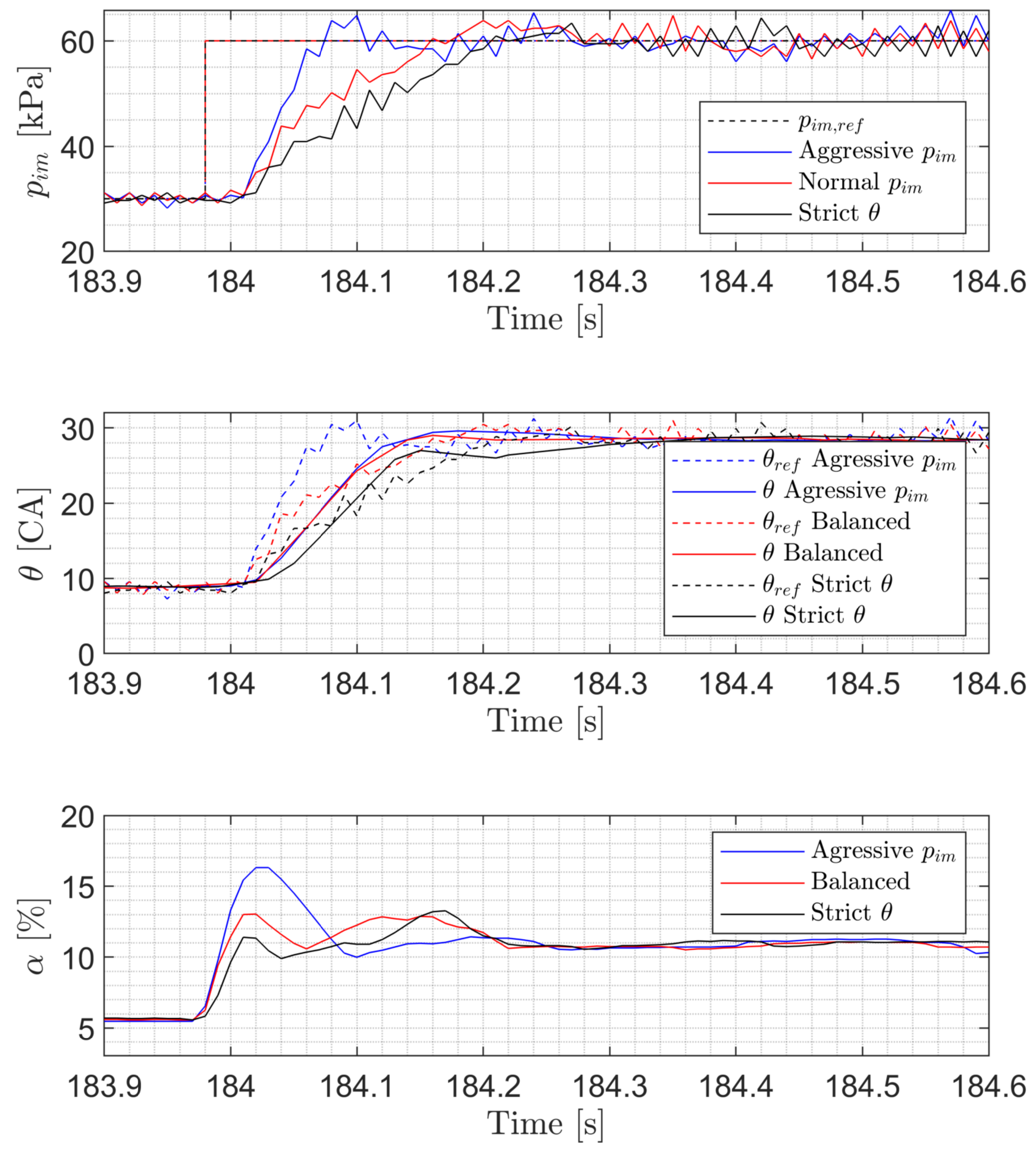
The previous figure is from Paper V[5] and displays the effects on the air mass flow, from the intake manifold pressure and intake cam phasing. The increase in air mass flow corresponds to an unwanted torque increase during the negative transient.

A component and model-based methodology were chosen in the thesis, as it would bring flexibility and the possibility to reuse previous development.

To be precise in the control of the air mass flow, the actuators are also constantly developed and becoming both faster and more precise. One example of this is the wastegate investigation in Paper I[1].

The air-charge system's task is to supply the combustion chamber with the correct air mass flow, in the most energy efficient way. Air mass flow models are investigated in Paper II[2] and III[3], where Paper II focuses on compact compressible flow models, used to model throttles, EGR valves, wastegates, poppet valves, etc.

Paper III focuses on modeling the volumetric efficiency with a dependency on actuation of the cam phasing. In the last part of the thesis, Paper IV[4] and V[5], model predictive controllers (MPC) are used as reference governors to control the system with different constraints active. In Paper IV the throttle is controlled to fulfill an intake manifold pressure demand while keeping down the intake manifold peak temperature.



Paper V demonstrates a real-time implementation of MPC, that controls both the intake cam phasing (θ) and the throttle (α), to fulfill an intake manifold pressure (p_{im}) demand, while having a constraint for the intake cam phasing that depends on the intake manifold pressure. Above figure demonstrates different weights on error in p_{im}, in the MPC formulation, resulting in different behaviors.

Included Papers

- *[1] Investigation of Performance Differences and Control Synthesis for Servo Controlled and Vacuum Actuated Wastegates.* Robin Holmbom, Bohan Liang, Lars Eriksson. SAE 2017 WCX Technical Paper 2017-01-0592.
- *[2] Analysis and Development of Compact Models for Mass Flows through Butterfly Throttle Valves.* Robin Holmbom, Lars Eriksson. SAE 2018 WCX Technical Paper 2018-01-0876.
- *[3] Development of a Control-Oriented Cylinder Air-Charge Model for Gasoline Engines with Dual Independent Cam Phasing.* Robin Holmbom, Lars Eriksson. Submitted to SAE WCX 2022.
- *[4] Throttle Control using NMPC with Soft Intake Temperature Constraint for Knock Mitigation.* Robin Holmbom, Lars Eriksson. E-COSM 2021.
- *[5] Real-Time Implementation of a Intake Manifold Pressure Controller with Dependence on Intake Cam Phaser using Nonlinear Model Predictive Control.* Robin Holmbom, Lars Eriksson. To be submitted.

LINKÖPING UNIVERSITY
LINK-SIC
LINKÖPING UNIVERSITY
DEPT. OF ELECTRICAL ENGINEERING