Cylinder Flow Estimation

The performance of air charge estimation algorithms in spark ignition automotive engines can be significantly enhanced using advanced estimation techniques available in the controls literature. This Chapter illustrates two approaches of this kind, that can improve the engine cylinder flow estimation. The first approach is based on an input observer while the second approach relies on an adaptive estimation. Assuming that the cylinder flow is nominally estimated via a speed-density calculation, and that the uncertainty is additive to the volumetric efficiency, the straightforward application of an input observer provides an easy-to-implement algorithm that corrects the nominal air flow estimate. The experimental results presented in this Chapter point to a sufficiently good transient behavior of the estimator. The signal quality may be deteriorating, however, for extremely fast transients. This motivates the development of an adaptive estimator that relies mostly on the feedforward speed-density calculation during transients while during engine operation close to steady-state conditions, it relies mostly on the adaptation. In our derivation of the adaptive estimator the uncertainty is modeled as an unknown parameter multiplying the intake manifold temperature. The tracking error between the measured and modeled intake manifold pressure together with an appropriately defined prediction error estimate are used in the adaptation algorithm with the improved identifiability and convergence rate. A robustness enhancement, via a $\sigma$-modification with the $\sigma$-factor depending on the prediction error estimate, ensures that in transients the parameter estimate converges to a pre-determined a priori value. In close to steady-state conditions, the $\sigma$-modification is rendered essentially inactive and the evolution of the parameter estimate is determined by both tracking error and prediction error estimate. Further enhancements are made by incorporating a functional dependence of the a priori value on the intake manifold pressure. The coefficients of this function can be learned in the process of engine operation from the values to which the parameter estimate happens to converge in close to steady-state conditions. This feedforward learning functionality improves
transient estimation accuracy and reduces the convergence time of the parameter estimate.

2.1 Introduction

The accuracy of engine air charge determination has a direct impact on the quality of the air-to-fuel ratio control, on the torque estimation and hence on the engine output performance. Good air charge estimation accuracy is therefore necessary to meet ever more aggressive emission and drivability targets. Inaccurate air charge estimation may also negatively affect a fuel economy if the spark timing is not set to the best efficiency at given engine operating conditions. With the introduction of new technologies such as variable valve timing, continuously variable valve lift, cam profile switching, variable geometry intake manifold, cylinder deactivation, boost on demand, variable geometry turbocharging, etc., a renewed interest is now paid to improving charge estimation algorithms to enable them to handle significant variations in volumetric efficiency and intake manifold temperature that may occur during transient operation of advanced engines. Of particular importance is also the ability of the algorithms to correct on-line for calibration inaccuracy that may be caused by part-to-part hardware variability, late in the development process hardware changes, aging, shortened development times.

The engine configuration considered in this work is shown schematically in Figure 2.1. Note that the engine has no external exhaust gas recirculation (EGR): Three-Way Catalyst and internal exhaust gas recirculation via, for example, an optimized valve timing schedule are assumed to sufficiently reduce feedgas emissions of nitric oxides. On the intake side, the engine is equipped with the mass air flow (MAF) sensor and with the intake manifold pressure (MAP) sensor. The temperature of air in the intake manifold is either measured or estimated.

Based on the intake manifold pressure measurement, the cylinder air flow can be estimated using the so called speed-density equation:

\[ m_{cyl} = \eta_v \frac{n_e V_d p}{RT}, \]  

(2.1)

where \( m_{cyl} \) is the mean-value of the flow into the engine cylinders (g/s), \( n_e \) is the engine speed (rev/s), \( p \) is the intake manifold pressure (kPa), \( T \) is the intake manifold temperature (deg K), \( R \) is the difference of specific heats (kJ/kg/K), \( \eta_v \) is the volumetric efficiency, and \( V_d \) is the displacement volume, i.e., the volume displaced by the engine cylinders during one engine cycle. The air charge per cylinder for a four stroke engine is estimated as

\[ M_{cyl} = m_{cyl} \frac{2}{n_e n_{cyl}}, \]