The main components, the main control tasks and a resulting control-oriented block diagram for turbocharged diesel engines were already discussed in Sect. 1.3.1. As depicted in the block diagram Fig. 1.3.7, in the software structure in Figs. 5.1.4 and 5.1.5 and in the hierarchical control structure of an ECU in Fig. 5.1.6 the control of diesel engines can be subdivided in:

- Torque control
  - fuel injection control
    - fuel mass control
    - injection angle control
    - injection pressure control
    - multiple injection control
  - air mass control
  - charging pressure control
  - variable valve control (if available)
- Emission control
  - exhaust recirculation control
  - particulate filter or SCR control
- Smoke limitation control
- Idle speed control
- Coolant temperature control.

The diesel engine operates with internal mixture formation and compression ignition. During the compression stroke the air from the intake is compressed to \(30 \ldots 55\) bar in naturally aspirating, or \(80 \ldots 110\) bar in charged engines and therefore the air heats up to about \(700 \ldots 900\) °C, according to compression ratios of 6:1 to 24:1. The fuel is injected shortly before the TDC and is auto-ignited by the warm air. The injected fuel spray leads to a heterogeneous combustion, based on finely atomized and easily combustible fuel droplets. The cylinder charge heats up and the cylinder pressure rises more, leading to pressure forces at the piston. The local air-fuel ratio varies between \(\lambda = \infty\) for pure air and \(\lambda = 0\) for pure fuel in the spray core. A combustion
arises in the range of $0.3 < \lambda < 1.5$ around the fuel droplets. Herewith the combustible mixture develops by diffusion and turbulence. The kind of the injected fuel spray and its kinetic energy have a large influence on the combustion.

In former times partial combustion started in a prechamber to obtain a good mixture in the main combustion chamber. Modern direct injection diesel engines form the mixture by the air movement and turbulence in the intake channel and valve contraction, the piston movement and the injected jet. High injection pressures up to 2000 bar, multi-hole injector nozzles and swirl and tumble supported by the design of the intake duct and the piston recess enable a good mixture formation.

The combustion process can be subdivided into three phases, Merker et al (2006). Firstly, the fuel jet mixes with the air and combusts very quickly after an ignition delay (pre-mixed combustion). The air/fuel mixture then continues and the combustion is determined by the mixing rate (diffusion combustion). Towards the end of combustion the burning becomes relatively slow (post-combustion). In this third phase intermediate products are further oxidized and especially previously formed soot is oxidized. This is described in more detail in Sect. 8.2.2. A pilot injection before the main injection enables to reduce combustion noise and allows an optimization of the main injection(s), which results in fuel savings and lower emissions.

Unlike gasoline engines the air flow is not throttled, such avoiding low pressure charge losses and the combustion is performed with large air excess factors of about $1.2 < \lambda < 10$. The torque is mainly determined by the injected fuel mass.

**On the contents of this chapter**

The chapter begins by describing the diesel-engine control structure and its various operating modes. Some simplified torque models are derived, and the measured stationary overall behavior and the dynamic behavior after step changes of four important input variables and 20 output variables is illustrated. Combustion models are treated for the pre-mixed and diffusion combustion for the assumption of one cylinder zone. Then, the optimization of the feedforward control with three main manipulated variables is considered for fixed operating points and a driving cycle by using numerical optimization methods, different criteria and model-identification methods. In order to meet the emission limits and to achieve good fuel consumption and acceleration, modern passenger car diesel engines are equipped with external exhaust gas recirculation (EGR) and with variable geometry turbochargers (VGT). The EGR mass flow is used to decrease the nitrogen oxide emissions. The turbocharger mainly increases the intake manifold pressure and, thus, increases the engine power.

A detailed presentation of the model-based design of a two-variable control system for the charging pressure and air flow rate describes how with identified local models and a combination of dynamic feedforward and feedback controls a precise control over the whole operating range can be reached.

The development of a combustion pressure heat release control opens ways for a feedback control of individual cylinder combustions. Adaptive look-up tables allow to improve the fixed feedforward look-up tables individually for all cylinders. It is then shown how a combustion-pressure-based control system can be realized to con-