tutorial

Injection Strategies for Compression Ignition (Diesel) Engines

Part I: Common-Rail Injection

Bruce Chehroudi, *Raytheon*

In the past decade we have witnessed an explosive growth in strategies to reduce the emission of harmful products of combustion from engines, in particular those used in the automotive industry. In this short article some fuel injection strategies found to be effective in reducing emission of pollutants while minimally compromising the performance and efficiencies are reviewed.

Traditionally, diesel engines are known to be a major contributor of particulate emissions. Particulates come from three sources: fuel carbon, soluble organic fraction derived from fuel and lubrication oil, and sulfate from the oxidation of sulfur in the fuel. Particulate and oxides of nitrogen are now stringently regulated in advanced and many developing countries. In additions, recent concerns on global warming, primarily with respect to carbon dioxide, have brought a greater impetus to consider lean-burn engines. A diesel engine burns overall lean (i.e. more air than theoretically required to burn the trapped fuel in each cylinder) and hence emits much less carbon monoxide and dioxide than a stoichiometric gasoline engine. Recent advances in injection strategies use the common-rail injection system with capabilities for pilot and split injection. Cam-driven fuel injection pumps such as in-line pumps, distributor pumps, unit pumps, and unit injectors have been used for many years. They build injection pressure through a small cylinder-piston mechanism (named barrel-plunger) for each injection event. The amount of fuel through the injector depends on the differential pressure across the injector holes. Because the injection piston (plunger) velocity is proportional to the engine speed, the fuel metering and pressure buildup are not independent. This is one major handicap of the aforementioned injection systems. In addition, they generally provide only a limited injection pressure at low engine speeds. Maintaining sufficiently high injection pressure at all speeds is critical for good liquid fuel atomization, in-cylinder fuel/air mixing, and reduced particulate emission. For these reasons a new injection system has been developed in the last decade and is named the common-rail fuel injection system. In essence a high-pressure fuel pump continuously operates to build pressure in a rail (or an accumulator) to which all the individual cylinder injectors are connected. The pressure oscillations generated by the fuel pump and the injection of the fuel through the injectors are damped by the rail volume. This concept is very similar to the modern port fuel injection of the gasoline-fueled engines but operates at much higher injection pressures (130 to 160 MPa versus 0.3 to 0.4 MPa). The injected fuel quantity is decided by the driver and the start of injection and injection pressure are calculated by the Electronic Control Unit (ECU) according to the stored maps.

General positive attributes of the common-rail injection system are listed in the following:

1. No relationship between injection pressure and engine speed.
2. Flexibility with regard to the injection pressure over the full engine speed range.
3. Higher specific output.
4. Better fuel consumption.
5. High injection pressures at low engine speeds resulting in improved engine torque and reduced engine noise.
6. Allows more freedom in engine control strategy based on sensor information.
7. Pressure generation and fuel injection are decoupled. Injection pressure, timing, and the fuel quantity can all be changed independently and with high degree of accuracy.
8. The fuel pump is not timed with the engine camshaft. Hence, more freedom with the choice of the drive system.
9. Unique potential for pilot and split injection.

However, a disadvantage of this high-pressure injection system is the requirement of very tight tolerances in design and manufacturing processes. This accounts for the increased cost of the engine using this injection system.

In addition to the aforementioned attributes, possibilities for injection strategies such as pilot and split injection exist when combined with a new injector design. Discussion of these strategies will be the subject of the second part of this series.