Medium/Heavy Duty
Truck Engines, Fuel &
Computerized Management
Systems, 3E

Chapter 19
Overview of
Diesel Fuel Injection Basics
Objectives

- Develop an Understanding:
  - The fuel system & fuel management system.
  - The fuel metering system.
  - Fuel atomization:
    - Required droplet sizing for diesel engines.
    - Factors determining emitted droplet sizing.
  - Engine “timing” & performance optimization through variable timing.
  - Cylinder pressures:
    - Relationship to crank throw & crank angle axis.
    - Fuel system relationship.
Diesel Fuel Injection Principles

- Diesel Engine Fuel Management
  - **Hydromechanical** – managed without a computer
  - **Electronic** – managed by a computer (ECM)

- Critical Considerations:
  - Timing
  - Pressurization & Atomization
  - Metering
  - Distribution
Fuel Delivery Timing

Diesel Engine Development

• Earlier Generations
  • Indirect Injection (IDI)
  • Low-tech Injectors
  • Pre-chambers used
  • BTDC (non variable)

• Fixed timing (+++advanced)

• Fuel as injected:
  • Larger droplets
  • Relies on turbulence in pre-chambers to break-down fuel droplets
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  - Direct Injection (DI)
  - BTDC (most, variable)
- Variable timing managed:
  - Mechanically
  - Hydraulically
  - Higher injection pressures
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## Fuel Delivery Timing

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#### Current Generation
- Direct Injection (DI)
- BTDC (variable)

- Variable timing managed:
  - Electronically
  - Multi pulse injection

- Higher injection pressures
- Smaller droplets
Multi Pulse Injection

Controlled by ECM

- Several separate injection events during one cycle
  - **Pilot Pulse**
    - Short initial pulse of fuel
    - Time of ignition is calculated by ECM
  - **Main Injection**
    - Resumes after pilot pulse of fuel is ignited
    - May be broken into successive injection pulses (up to seven) managed by the ECM
  - **Successive pulses:**
    - Make efficient use of cylinder heat energy
    - Minimize emissions
    - Smooth application of force to the piston
Emissions & Engine Timing

- Timing of fuel injection influences tailpipe emissions.
- A strategy that minimizes one emission may have a counter-productive effect on another aspect of emissions.
Emissions & Engine Timing

✓ Advanced Timing  
  = More complete fuel burn.  
  = Reduced hydrocarbon (HC) emissions.  
  = Higher cylinder temperatures.
Emissions & Engine Timing

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  - Production of NOx compounds.

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- **Retarded timing**
  - Lower cylinder temperatures.
  - Reduces production of NOx.
  - Less “burn” time.
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  - Higher HC & exhaust soot.
Pressure & Atomization

**Fuel Atomization:**
- Is accomplished by pushing pressurized fuel through injector orifii.
- Is necessary to prepare the fuel charge for combustion.
- The degree of atomization is defined by droplet size.

**Droplet Size Determined By:**
- Fuel pressure at the orifii
- Flow area or sizing of the injector nozzle orifii
Fuel Injection Pump

Fuel pumping apparatus:
- Actuated mechanically.
- Produce up to 35,000 psi (2450 bar) peak pressures.
- Produce peak pressures regardless of engine R.P.M.
- Types:
  - Single high pressure pump.
  - Pumping elements dedicated to each cylinder

Fuel pump drive may be either:
- Engine timing gear train
- Main engine camshaft
Engine Management

- Expectations:
  - ✓ Engine must meet stringent emissions standards.
  - ✓ Engine performance must be optimized.
  - ✓ Fuel economy must be maximized.

- These factors are determined by droplet size.
- This process is managed by the ECM.
Droplet Size

- Droplet size influences burn rate.
- The greater surface area of the larger droplet increases the time required to achieve optimum mixing of the fuel and oxygen.
Fuel & The Burning Process

- Fuel droplets burn from the outside in.
- Larger droplets require more time to completely burn.
- Larger droplets must be injected “more advanced” to ensure the proper burn during the power stroke.
- Smaller droplets respond more rapidly to cylinder heat & take less time to completely burn.
Fuel Metering

- Diesel engines require the precise control of fuel quantity admitted to the engine.

- Diesel engines operate with excess air.
- Given unlimited fuel, most diesel engines will accelerate at an approximate rate of 1000 R.P.M.

This will inevitably lead to self-destruction!
Fuel Metering

- Metering is accomplished by:
  - Injection Rate:
    - The quantity of fuel injected per crank degree angle.
    - Preferred method in older hydromechanically controlled diesel engines.
  - Duty Cycle:
    - Used in electronically controlled engines
    - Displayed as “Pulse Width” (PW) & measured in milliseconds with electronic service tools (EST).
Fuel Distribution

- Fuel must be delivered to each engine cylinder:
  - At the correct time (phased).
  - In the proper firing order (sequentially).
  - To the correct area of the combustion chamber.

- Correct fuel phasing is required to balance engine output.

- Fuel must be delivered sufficiently in advance of the ECM’s computed optimum ignition point to ensure ignition occurs at exactly the precise time.
Service Tip

- The incorrect placement of an injector in its seat could result in:
  - Improper spray dispersion
  - Fuel injected above combustion bowl causing:
    - Fuel condensation on the piston headland
    - Fuel condensation on the cylinder walls
  - Condensed fuel can boil during the combustion process resulting in erosion (pitting)!

Ensure the injector cavity is free from obstructions when removing & replacing injectors!
Engine Output Objectives

- The fuel system manages engine output.
  - Power must be delivered smoothly & evenly to the flywheel.
  - Engine “fueling” must complement the geometry of the crankshaft.
For optimal performance the crank leverage and cylinder pressure compliment each other.
Engine Geometry

- Crankshaft Leverage
  - The relationship of the crank throw (connecting rod journal) & the crank axis (centerline) forms a lever
  - The greater the “offset” the greater the leverage
  - AT TDC, the leverage is zero
  - As the crank turns, the leverage increases
  - Reaches maximum leverage at 90° ATDC
Cylinder Pressure

- “Smooth & Even” application of torque is a primary objective of an engine.
- Proper development & application of cylinder pressure is a key factor in the successful delivery on this objective.

- Ideal Circumstance:
  - Cylinder pressure peaks at the crankshaft’s low mechanical advantage position (10°-20° ATDC).
  - Decreasing pressure as the crankshaft gains mechanical advantage (to 90° ATDC)
Synchronizing Pressure & Leverage

- Traditional:
  - Advance ignition or injection timing.

- Current Electronic
  - Advance injection timing
  - Control Fuel metering
  - Control injection activity

Today’s engines perform these tasks in milli & microseconds, thanks to the capabilities of the ECM!
Domestic OEM diesel engines are engineered using the Metric system measurement. These measurements are currently converted to “Standard” measurement for manuals & service literature.

Today’s technician needs to be familiar & understand both methods of measurement!
Summary

- Smooth & even engine power is developed only if:
  - The fuel system is accurately phased.
  - The fuel is delivered to the correct cylinder at the correct time.
  - The fuel delivered is precisely metered.

- Diesel fuel systems:
  - Must be capable of atomizing fuel to precise dimensions.
  - Produce pressures exceeding 35,000 psi.

- Atomized diesel fuel:
  - Is in a liquid state.
  - Droplets burn from the outside in.
  - Larger droplets take longer to completely combust.
  - Ignition of the fuel takes places after the fuel is vaporized by the cylinder heat & subsequently ignited by that heat.
Summary Continued

- The ECM provides:
  - Continuous variable timing to provide optimum performance under changing operating conditions.
  - Precisely atomized fuel droplet size through controlled injection pressures related to injector orifice size.
  - An ability to manage cylinder pressures.
  - The calculations to ensure the cylinder pressure to “peaks” at 10 to 20 degrees ATDC.

- The crankshaft:
  - Is a lever
  - The relationship between cylinder pressure & crank throw leverage produces torque.