Fuel Injection Basics and Governor Principles
Chapter 20

Instructor Name: (Your Name)
OBJECTIVES

• Understand the objectives of a fuel management system.

• Interpret the contents of later chapters dealing with hydromechanical and electronic engine management.

• Define timing and explain the need to vary it for optimum performance and emissions.
OBJECTIVES (Cont.)

• Define metering and its application in a fuel system.

• Explain atomization and the droplet sizings required for a direct-injected diesel engine.

• Describe the factors that determine emitted droplet sizing.
OBJECTIVES (Cont.)

• Explain the overall objectives of an engine fuel system.

• Describe the relationship between cylinder pressure and crank throw to crank axis angle.

• Relate how the fuel system manages engine cylinder pressures.
OBJECTIVES (Cont.)

• Describe the relationship between pumping, injection, and combustion in hydromechanical and electronic engines.

• Understand why “smart” injector nozzles are required on most post-2007 diesel engines.

• Outline the reasons why diesel engines have to be governed.
OBJECTIVES (Cont.)

• Classify governors by management mode.

• Interpret electronic governor performance terminology.

• Interpret a flat profile diesel engine fuel map.
OVERVIEW OF DIESEL FUEL INJECTION PRINCIPLES

• The fuel system manages the engine.

• The timing and quantity of fuel introduced into the engine cylinders determine: Engine power and engine emissions.
OVERVIEW OF DIESEL FUEL INJECTION PRINCIPLES

Diesel engines can be managed in two ways:

1. Hydromechanical engine management (engines managed without a computer).

2. Electronic management (engines managed by computer).
Managing Fueling Outcomes

• Timing

• Pressurizing and atomization

• Metering

• Distribution
Managing Fueling Outcomes

• Timing, Fuel delivery timing is critical during all engine operating phases.

• Typically, fuel injection begins just slightly before the piston completes its compression stroke.
Managing Fueling Outcomes

• In addition, almost all current diesel engines use multipulse injection timing.

• Pilot Injection.

• Multipulse Injection.
Timing and Emissions

- In a general sense, the timing of fuel injection also influences tailpipe emissions.
  - Advanced injection timing.
  - Retarded timing.
Timing and Emissions (Cont.)

Pressurizing and Atomization

- The pressure of the fuel supplied to the nozzle orifii.
- The flow area or sizing of the nozzle orifii.
- Droplet Size, Fuel droplets burn from the outside in.
Fuel droplets burn from the outside in: large droplets take longer to completely burn.
Timing and Emissions (Cont.)

Metering

• **Metering** is the precise control of fuel quantity.
Timing and Emissions (Cont.)

When technicians refer to the metering of fuel into diesel engine cylinders two methods are used:

1. **Injection rate** is the fuel quantity injected per crank angle degree.

2. **Duty cycle** is a more commonly-used term today to describe metering in electronically controlled diesels.
Timing and Emissions (Cont.)

Distribution

• The fuel system must be phased (sequenced) to deliver the fuel to each engine cylinder at the correct time and in the correct firing order.

• The fuel must be dispensed to the correct area of the combustion chamber so that the fuel droplets combust at the appropriate time.
The fuel system manages engine output.

- Throw Leverage
- Cylinder Pressure
- Synchronizing Pressure with Leverage
The diagram above depicts the angle between the crank throw and piston travel plane: this should not be confused with crank angle degrees ATDC.

<table>
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<th>Throw vector angle</th>
<th>0°</th>
<th>15°</th>
<th>45°</th>
<th>90°</th>
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<tr>
<td>Leverage</td>
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<td>Minimal</td>
<td>Increasing</td>
<td>Maximum</td>
</tr>
<tr>
<td>Ideal cylinder pressure</td>
<td>Zero</td>
<td>Maximum</td>
<td>Decreasing</td>
<td>Decreasing</td>
</tr>
</tbody>
</table>

- Crankshaft axis and main bearing center
- Crank throw
The function of any diesel fuel injection system is to manage the fueling of an engine so that it produces the desired performance outcomes.
Regardless of the actual fuel system, the timing and volume of fuel injected to the engine cylinders determine:

- When combustion takes place
- The intensity of combustion and resulting cylinder pressures
- The duration of combustion
DELIVERY, INJECTION, AND COMBUSTION (Cont.)

- Until the introduction of **common rail (CR)** fueling, whether an engine is managed hydromechanically or electronically, the events of injection and combustion are managed by what is happening in the high-pressure pump.
DELIVERY, INJECTION, AND COMBUSTION (Cont.)
INJECTION LAG

• **Injection lag** is the time measured in crank angle degrees an effective stroke in the injection pump (such as PLN, EUI, HEUI, or EUP) and the moment the injector nozzle opens to begin injection.

• It is primarily accounted for by the time required to raise pump chamber pressure (charging pressure) to the NOP value.
IGNITION LAG

- **Ignition lag** is the time period between the events of NOP and the point at which the fuel charge is ignited.

- It can be measured in crank angle degrees or fractions of a second.
IGNITION LAG (Cont.)

Ignition lag real time depends on:

• The size of the atomized droplets

• The quality of the fuel

• The actual temperature in the cylinder
The duration of combustion depends on:

- The length of the injection pulse, which determines fuel quantity per cycle (hydromechanical and first-generation electronic engines).
- The duration, pressure, and number of injection pulses in a fueling cycle (current electronic engines).
NOZZLE CLOSURE LAG

• **Nozzle closure lag** is the time period between the end of injection pump delivery and actual nozzle closure.

• Throughout the nozzle closure lag, combustion in the engine cylinder continues.
“Smart” Nozzles

• A few on-highway EPA-certified commercial diesels after 2007 use hydraulic nozzles.

• The exceptions are the few hydraulically actuated, electronic unit injector (HEUI) fueled engines that remain in production.
AFTERBURN

• **Afterburn** is the normal combustion of fuel in the engine cylinder after injection nozzle closure.

• In current electronic management systems with smart nozzles, undesirable afterburn is eliminated by keeping the droplet sizing small at the end of the injection event.
GOVERNING OBJECTIVES

• At the beginning of this chapter, we said that the output of any diesel engine is limited only by the quantity of fuel injected into its cylinders.

• This is because diesel engines are aspirated with excess air.

• This makes managing the amount of fuel injected into the cylinders of a diesel engine critical.
The primary function of a diesel engine governor is to sense engine speed and limit fueling when the engine is run at its specified maximum speed.

Today, electronic governors are used on all highway, and most off-highway, diesel engines.
An electronic governor manages engine output based on command inputs from the vehicle operator and the range of sensor signaling information sent to the ECM.

The governor software (in the engine ECM) then maps a fueling profile.
The fueling profile is the set of output commands that control such things as:

- Fuel quantity
- Injection timing
- Pilot and multipulse injection events
The ECM in a truck diesel engine is responsible for both the “thinking” (computations) and switching (actuation) required of a computer.

When we talk about an ECM’s role in governing engine output, we should identify two distinct phases:
1. The “processing” (thinking) phase. Engine OEMs call this the governing algorithm.

2. The switching phase. After the ECM has processed the governing algorithm, this has to be converted into action by the ECM switching apparatus.
WHAT GOVERNORS DO

• A governor determines how an engine is fueled.

• At minimum, it limits fueling at the highest intended engine rpm to prevent overspeed.

• In addition, it is also required to define the lowest no-load rpm of the engine to enable the engine to idle without any input from the driver’s accelerator pedal.
TORQUE RISE

• The normal engine operating rpm is the range of the rpm spectrum where the engine OEM calculates that the engine should be operated to produce the best combination of power and fuel economy.

• As truck technicians, we call this *torque rise rpm*. 
Fuel Maps

• This engine has its fuel system set up to produce peak torque at 1,400 rpm and rated power at 1,800 rpm.

• The torque rise profile on this engine is therefore between 1,400 and 1,800 rpm.
Fuel Map

- Peak torque
- Rated power
- High idle (TEL)
- Torque rise profile
- LUG
- Droop curve
- Governor overrun

Fuel quantity per cycle vs. Engine RPM
RATED SPEED AND LOAD

• In highway truck applications, peak horsepower is expressed as rated power, but more often engine OEMs use the term *rated speed*.

• If the peak power in an engine is 600 horsepower at 1,800 rpm, this could also be referred to as the rated speed.
DROOP CURVE

• **Rated speed** is the highest rpm at which a diesel engine should be operated, and most ECM-managed engines will only allow engine rpm to run above rated speed under exceptional circumstances.

• However, all diesel engines powering mobile equipment are top-end governed with droop curve.
LUG

• An engine is put into a *lug mode* when the rpm drops below the lowest rpm in the intended engine-operating range.

• This is known as *lugging*, and it occurs when engine load drops the rpm below the base rpm of torque rise.
START-UP STRATEGY

• A generation ago, cold-start strategy meant providing excess, usually absolute full fuel during cranking.

• Today, cold-start strategy is precisely managed by the governor software, and input from the operator such as flooring the accelerator pedal is ignored.
OEM Management Systems

• Electronic governing is used by all of today’s diesel engine electronic management systems.

• It goes by names such as Detroit Diesel/Mercedes-Benz DDEC, Cummins CELECT and IS (Interact System), Caterpillar ADEM and ACERT, Mack Trucks V-MAC, Navistar Diamond Logic, Volvo VECTRO, and Paccar MX.
GOVERNOR CLASSIFICATIONS

• Any governor is classified by how it manages engine performance.

• This has changed. With an EST and the appropriate software, a few keystrokes can radically change how an engine is governed.
A limiting speed governor (LSG) sets the engine idle speed, defines the high-idle speed, and permits fueling between those values to be controlled by an operator (driver).

LSGs are the most common in commercial vehicle applications.
TECH TIP

• Accelerator pedal angle in an LSG-managed truck diesel engine defines a fuel quantity.

• If the driver wants either more or less fuel, the pedal angle must be either increased or decreased.
**VARIABLE SPEED (VS)**

- A **variable speed governor (VSG)** sets engine idle speed and defines high idle and any speed in the intermediate range depending on accelerator pedal position.

- A given amount of accelerator pedal travel corresponds to an engine rotational speed.

- As engine loading either increases or decreases, the governor software manages fueling to attempt to maintain that engine speed.
Driving with VS Governing

• Driving a vehicle with VS governing is often the preference of more experienced truck drivers because it ultimately requires less effort.

• Accelerator pedal angle is essentially a “request” for a specific engine rpm, so within the capabilities of the fuel system, this request will be effected.
Accelerator pedal angle in a VS-managed truck diesel engine requests a specific engine rpm. Within the limitations of the fuel system, the governor attempts to maintain that rpm as engine load conditions change.

Driving a VS-managed engine requires a smoother foot on the accelerator pedal.
CAUTION

• Try to identify the governor type or programming before driving any truck.

• If you attempt to drive a VS-governed truck engine by handling the accelerator pedal in the same way as that in your car, the result will be a truck that bucks and lurches, sometimes leaving the driver bouncing uncontrollably on an air suspended seat.
CAUTION (Cont.)

• This is because each time the accelerator pedal angle changes, you are signaling a request for a different engine rpm.

• Do this fast enough, and you will confuse even the fastest-responding engine ECM.
GOVERNOR
PROGRAMMING OPTIONS

• In the days when a governor was a piece of hardware, adjustments were required from time to time.

• In those days, we referred to the adjustments as *trim options*. 
GOVERNOR PROGRAMMING OPTIONS (Cont.)

The way in which a diesel engine governor manages the engine can be changed in two ways:

1. Customer data programming

2. Proprietary data programming
Altitude Compensation

• All current engines have altitude compensation maps programmed into the governing software.

• As altitude increases, oxygen density begins to decrease.

• Electronically-managed engines use ambient pressure sensors that measure even minute changes in altitude, allowing the governor maps to adjust fueling immediately.
ROAD SPEED GOVERNING

All of today’s drive-by-wire commercial vehicles offer a range of road speed governing options.

• Road Speed
• Droop
• Soft Cruise
DEFAULT GOVERNING

• The term **default mode** is used to describe how the engine manages itself in the event of the loss of a key input sensor.

• The best example would be loss of throttle position sensor (TPS) input signal. Rather than shutting down the engine completely, the engine runs at a default speed, say 1,000 rpm, so that the vehicle can be safely maneuvered to a safe location on or off the highway.
OTHER GOVERNOR TERMS

- We have already introduced most of the key terms required to understand governor operation, but because of the ever-increasing programmability of governing fields in ECMs, some OEMs use other governor terms.
OTHER GOVERNOR TERMS (Cont.)

Some of the more popular governor terms are:

• Deadband

• Governor cutoff

• Hunting
OTHER GOVERNOR TERMS (Cont.)

• Motoring

• Overrun

• Overspeed

• Road speed governing (RSG)
OTHER GOVERNOR TERMS (Cont.)

• Sensitivity
• Speed drift
• Stability
• Underrun
• WOT
SUMMARY

• In any CI engine, a power stroke only takes place if the fuel system is accurately phased to the engine.

• Timing of fuel injection is ECM controlled in current diesel engines.

• This provides for continuously variable timing so that changes in engine-operating conditions can produce the best performance outcomes.
SUMMARY (Cont.)

• Current diesel fuel systems can produce injection pressures exceeding 35,000 psi, and this is expected to increase.

• Today’s engines provide the ECM with the ability to control the atomized fuel droplet size precisely.
SUMMARY (Cont.)

• When a hydraulic injector nozzle is used, the size of the emitted droplets depends on fuel pressure and the nozzle orifice size.

• Because the nozzle orifice size does not change, the pump element pressure determines the actual size of fuel droplets injected into an engine cylinder.
SUMMARY (Cont.)

• In more recent electronically managed engines, the ECM has the ability to control pump pressure.

• In most post-2007 EPA-compliant diesel engines, the ECM controls droplet sizing by either managing pump pressure (EUI and EUP systems) or by managing rail pressure (CR systems).
• Fuel droplets burn from the outside in. This means a larger atomized fuel droplet requires more real time to combust completely than does a smaller droplet.

• Fuel delivered to the engine cylinders must be precisely metered.

• The terms duty cycle and injection rate are key to understanding metering.
SUMMARY (Cont.)

• Duty cycle is the term used to describe metering duration in real time in most electronically-managed engines.

• It is usually measured in ms or crank angle degrees.

• Duty cycle is often displayed as pulse width (PW).
SUMMARY (Cont.)

• Injection rate refers to fuel injected per crank angle degree, and it is usually governed by the injection pump actuating mechanism geometry or by the ECM in cases where smart injectors are used.

• This term is more commonly used on hydromechanical engines.
SUMMARY (Cont.)

• A modern diesel engine fuel system must be capable of atomizing fuel to precise dimensions.

• Failure to achieve this will result in combustion problems.

• Atomized fuel is in the liquid state. After injection, atomized droplets are exposed to cylinder heat. They are first vaporized and then ignited by the heat in the cylinder.
SUMMARY (Cont.)

• The fuel system must deliver the fuel to the correct cylinder at the correct time to ensure balanced power output.

• The relationship between the crank throw and the crankshaft centerline is that of a lever.

• The ECM uses the fuel system to manage engine cylinder combustion pressures.
SUMMARY (Cont.)

• The combination of cylinder pressure and crank throw leverage produces torque.

• In a properly managed fuel system, torque applied to the flywheel should be smooth and even.
SUMMARY (Cont.)

• To optimize the relationship between cylinder pressure and mechanical advantage to provide smooth torque application, cylinder pressure should ideally peak between 10 and 20 degrees ATDC regardless of speed or load conditions.

• A four-stroke cycle engine run at 2,000 rpm will produce approximately 17 power strokes per second in each of its cylinders.
SUMMARY (Cont.)

• Understanding how pumping, injection, and combustion relate to each other is a key to understanding engine management.

• Diesel engine governors, whether electronic or hydromechanical, must be able to sense engine speed and be capable of modulating engine fueling in the event of an overspeed condition.
SUMMARY (Cont.)

• Because the output of any diesel engine is determined by the fuel quantity metered into its cylinders, a fuel map graph can be helpful when it comes to understanding governor operation.

• An LS governor can also be referred to as an automotive or min-max governor.
SUMMARY (Cont.)

• Accelerator pedal angle in an LS-managed truck diesel engine defines a fuel quantity. If the driver wants either more or less fuel, the pedal angle must be either increased or decreased.

• A VS governor can also be referred to as an all speed or full-range governor.
SUMMARY (Cont.)

• On a VS governor, accelerator position requests a specific engine speed.

• As engine load increases and decreases, the governor adjusts engine fueling to attempt to maintain that set engine speed.

• VS governors are a programmable option to the ECM.
SUMMARY (Cont.)

• Accelerator pedal angle in a VS-managed truck diesel engine requests a specific engine rpm.

• Within the limitations of the fuel system, the governor attempts to maintain that rpm as engine load conditions change.

• Road speed governing is commonly specified in current truck engine applications.
SUMMARY (Cont.)

• Electronic governors are altered by reprogramming either by OEM or customer data programming.

• Older hydromechanical governors are altered by trim adjustments, sometimes requiring hardware changes.
ANY QUESTIONS?

Thank You!