Combustion Theory

Screen 1:
Introduction to Combustion Theory:
Welcome to the Combustion Theory module of the 7FDL Diesel Engine Basic course. Millions of engines are in use every day, the most common being the engines that power our cars. The lifestyles we all are accustomed to would be non-existent if it were not for the power provided by the internal combustion engine. With a device as important as this, it only makes sense that we should have a basic understanding of how a combustion engine operates.

At the end of this module, you will be able to:

- Describe how a combustion engine operates.
- List the differences between a gasoline engine and a diesel engine.
- Describe the four strokes of a diesel engine.

Screen 2:
Combustion Engine Theory:
The internal combustion engine is a device that utilizes a chemical reaction between a combustible fluid, better known as fuel, oxygen, and heat. This chemical reaction is used to produce captive, controlled, synchronized explosions. The energy produced by these explosions is used to rotate a primary shaft commonly called a crankshaft. While this may sound complicated, it really is not.

Screen 3:
Gasoline and Diesel Engines:
As with any product as all-encompassing as the combustion engine, variations and improvements have developed over time. One of the prominent and well-known deviations from the traditional gasoline engine was the development of the diesel engine. So, how is the diesel engine different from the gasoline engine?

Screen 4:
Gasoline vs Diesel:
Obviously, there is a difference between the types of fuel used for the gasoline and diesel engines. But another important difference is how ignition of the air-fuel mixture is initiated. The combustion chamber of a gasoline engine receives a mixture of gas and air and compresses it. The mixture is then ignited by means of an electronic ignition source, commonly called a spark plug. Like the gas engine, the combustion chamber of a diesel engine receives and compresses air but initially it is not mixed with fuel. Typically, the compression ratio of a diesel engine is higher than that of a gas engine. Due to this high compression ratio, the air reaches a temperature high enough to spontaneously ignite the fuel that is injected directly into the combustion chamber. No electronic ignition source is used to ignite the fuel.

Screen 5:
Gasoline vs Diesel (Cont'd):
Normally, a gasoline engine would have a compression ratio in a range of 8:1 to 12:1, while a diesel engine would normally compress at a ratio from 14:1 to 25:1. If the ratio is 8:1, you can think of this as taking a column of air that is 8 inches high and 1 inch wide, and compressing that column down

to a 1 inch high and 1 inch wide column. The higher compression ratio of the diesel engine leads to higher fuel efficiency. The higher compression ratio also raises the temperature of the compressed air.

Screen 6:
Gasoline vs Diesel (Cont'd):
Diesel engines use direct fuel injection, where the fuel is injected under high pressure directly into the combustion chamber when the air temperature is high enough to instantaneously ignite the fuel. Gasoline engines generally use carburetion or port fuel injection. Port fuel injection is where the fuel is injected in the intake air manifold just prior to the fuel entering the combustion chamber through the intake valve located outside the cylinder. Carburetion is where air and fuel are mixed long before they enter the combustion chamber.

Screen 7:
Four-Stroke Diesel Engine:
As with most automobile gasoline engines, our diesel engines are four-stroke-per-cycle engines, often referred to as simply four-stroke or four-cycle engines. Regardless of the naming convention used, one complete cycle of a four-stroke diesel engine includes four strokes of a piston inside a single cylinder: intake, compression, combustion, and exhaust. During the four strokes, there are three items needed for combustion: oxygen, heat, and fuel.

Screen 8:
Intake Stroke:
The intake stroke is the first stroke of the four-cycle diesel engine. During this stroke, the piston is traveling in a downward motion inside the cylinder. Intake valves located in the combustion chamber are open, allowing air to enter into the chamber. This provides oxygen-laden filtered air to the combustion chamber. The intake stroke provides oxygen, one of the three items needed for combustion.

Screen 9:
Compression Stroke:
The compression stroke is the second stroke of the four-cycle diesel engine. During this stroke, the piston has changed direction to initiate a new stroke, and is traveling in an upward motion in the cylinder. The intake and exhaust valves, located at the top of the combustion chamber, are closed, sealing off the combustion chamber. The piston is compressing the air that was drawn into the cylinder during the previous stroke, the intake stroke. As the air is compressed, the temperature increases rapidly to typically 700 to 1100 degrees Fahrenheit (approximately 370 to 590 degrees Celsius). This produces the second item needed for combustion, heat. At the end of the compression stroke, diesel fuel is injected into the combustion chamber at a very high pressure. Fuel, the third and last item, is now present for combustion. The fuel ignites spontaneously when the fuel mist comes into contact with the very hot air. This starts the third stroke of the cycle: combustion stroke. The crankshaft has now rotated one full turn.

Screen 10:
Combustion Stroke:
The combustion stroke is the third stroke of the four-cycle diesel engine. During this stroke, the piston is being forced in a downward motion in the cylinder by the rapid expansion of gases created by the ignited fuel. This energy is used to power the engine. This is the only stroke that

creates mechanical energy. The energy produced from the chemical reaction of the oxygen, heat and fuel is transformed into mechanical energy to rotate the crankshaft.

Screen 11:

Exhaust Stroke:

The exhaust stroke is the fourth and final stroke of the four-cycle diesel engine. During this stroke, the piston has changed directions, and again is traveling in an upward motion in the cylinder. The exhaust valves located in the combustion chamber are now open, allowing the piston to push the exhaust gases out of the combustion chamber and into the exhaust manifold. This completes the four strokes of the diesel engine. The crankshaft has rotated two complete turns to complete this cycle.

Screen 15:

Summary:

You have reached the end of this module!
In this module, you learned to:

- Describe how a combustion engine operates.
  - An internal combustion engine utilizes a chemical reaction between fuel, oxygen and heat. This chemical reaction is used to produce captive, controlled, synchronized explosions, which provide the energy to rotate the primary shaft commonly called a crankshaft.

- List the differences between a gasoline engine and a diesel engine.
  - A gasoline engine draws in a mixture of air and fuel into the combustion chamber, whereas a diesel engine initially charges the combustion chamber with just air.
  - In a gasoline engine an electronic ignition source is used for ignition, whereas no electrical ignition source is used to ignite the fuel in a diesel engine.
  - A diesel engine has a much higher compression ratio than a gasoline engine, which provides the high temperature to ignite the fuel.
  - Diesel engines use direct fuel injection while the gasoline engines generally use carburetion or port fuel injection.

- Describe the four strokes of a diesel engine.
  - In the intake stroke, the piston travels in a downward motion in the cylinder, allowing air to enter into the chamber.
  - In the compression stroke, the piston travels in an upward motion in the cylinder, compressing the air that was drawn into the cylinder during the previous stroke.
  - In the combustion stroke, the piston is being forced in a downward motion in the cylinder by the rapid expansion of gases created by the ignited fuel.
  - In the exhaust stroke, the piston travels in an upward motion in the cylinder, pushing the exhaust gases out of the combustion chamber.

7FDL Diesel Engine Overview

Screen 1:
Welcome Screen:
Welcome to the 7FDL Diesel Engine Overview module of the 7FDL Diesel Engine Basic course.

Screen 2:
Introduction to 7FDL Diesel Engine:
Engineering developed the 7FDL engine for use in diesel engine railroad locomotives. Its design and rating is based on extensive laboratory tests backed by millions of hours of field experience with thousands of engines in service today.

At the end of this module, you will be able to:

- State the information represented by the 7FDL engine classification.
- Define the terms associated with the 7FDL diesel engine orientation and cylinder locations.
- Recognize the differences in engine specifications for the 7FDL 12-cylinder and 16-cylinder engines.
- Explain how 7FDL engines have evolved to meet regulatory requirements.

Screen 3:
Overview of 7FDL Diesel Engine:
The letter-and-numeral code combination used to classify the 7FDL engine is based on the following:

- ‘7’ indicates our category of mechanical devices.
- ‘F’ represents the 9" engine cylinder bore and 10.5" piston stroke.
- ‘D’ stands for diesel.
- ‘L’ indicates that the engine is designed for a locomotive application.

If you are working on one of our diesel engines using the documentation provided with your locomotive, certain terms will be used to describe component locations. This module will familiarize you with the terms and locations described in official documentation.

Screen 4:
7FDL Engine Orientation:
The two ends of the diesel engine are referred to as the free end and the alternator end. The free end of the engine is the end where the turbocharger and intercoolers are mounted. This end faces the radiator cab when the engine is mounted on the locomotive. The generator or alternator end is the end of the engine where the generator or alternator is mounted. This end of the engine is oriented towards the operator's cab.

Screen 5:
7FDL Engine Orientation (Cont’d):
The cylinders are numbered from the free end to the alternator or generator end of the engine. The No. 1 right and No. 1 left cylinders are nearest the turbocharger on all our diesel engines. The right side or left side of the engine is determined when viewing the engine while facing the generator or

alternator end of the engine. The right side of the engine is on the left side of the locomotive. During engine operation, the crankshaft rotates counterclockwise when viewed from the alternator end and clockwise when viewed from the free end.

Screen 6:

Engine Specifications:

The specifications, dimensions and weights of the 7FDL 12-cylinder and 16-cylinder diesel engines are shown in the table. The 12- and 16- cylinder engines are similar on many counts but differ with regard to number of cylinders and their firing order, and also their length and weight. The 7FDL diesel engine has undergone numerous improvements in its 50-plus years of locomotive history. Recently, the changes made to the 7FDL diesel engine have been driven by evolving exhaust emission regulatory standards that govern the locomotive freight hauling industry.

Screen 7:

7FDL Tier 0 Compliant Engines:

To reduce the emissions from locomotives, the United States Environmental Protection Agency (EPA) first issued a set of standards in 1973, referred to as the Tier 0 Standards.

- The primary focus of the EPA regulations is the reduction of nitrogen oxides or NOx. Also measured and regulated are hydrocarbons, carbon monoxide, particulate matter, and smoke.
- These pollutants are measured in weight (grams) of pollutants emitted to produce 1 horsepower for 1 hour. The table displays the EPA Tier 0 limits for these pollutants.

Although the Tier 0 standards were issued in 1973, they did not become effective until 2000, which allowed manufacturers time for the design and development of new engines to meet the standards.

Screen 8:

7FDL Tier 0 Compliant Engines (Cont'd):

To meet the Tier 0 standards, modified 7FDL diesel engines were first put into production on January 1st, 2001. All 7FDL engines manufactured between January 1st, 2001 and December 31st, 2001, were compliant with Tier 0 emission standards. Once the Tier 0 standards became effective in 2000, the standards also applied to all locomotive engines originally manufactured from 1973 through 2001, and included both newly manufactured and remanufactured engines.

Screen 9:

7FDL Tier 1 Compliant Engines:

Beginning in January of 2002, all 7FDL diesel engines placed into production through 2004 complied with the EPA Tier 1 regulations. Going from Tier 0 to Tier 1 represented a 22% reduction in NOx and a 25% reduction in particulate matter. The table displays the EPA Tier 1 limits for these pollutants. In order to meet the Tier 2 standards that became effective in 2005, Engineering introduced the Evolution Series of locomotives in North America, replacing the Dash 9 and AC4400 locomotives, both of which used the 7FDL engine.

Screen 10:
7FDL Tier 0+ and 1+ Compliant Engines:
In 2008, the emission standards were modified and the revised Tier 0 and Tier 1 were designated as Tier 0+ and Tier 1+. These revised guidelines are applicable to 7FDL engines that were originally produced between 1993 and 2004, but are remanufactured as of January 1st, 2010. The revised guidelines are documented in the United States Code of Federal Regulations (CFR), Title 40, Part 1033. For ease of reference, this regulation is referred to as 40 CFR Part 1033. Part 1033 deals specifically with the control of emissions from locomotives. There are currently two different versions of Part 1033-compliant 7FDL diesel engines; the Tier 0+ and the Tier 1+ compliant engines. Differences between the two versions of diesel engines are that Tier 0+ versions maintain the Tier 0 camshaft assemblies and turbochargers. NOx credits allow for a limited number of engines to keep the Tier 0 camshaft assemblies and turbochargers. These units would be Part 1033 Tier 0+ compliant units. The Part 1033 regulation reduces the emissions of particulate matter by approximately 50% from the Tier 1 limits.

Screen 11:
Emission Critical Components:
Certain parts and assemblies on our locomotives manufactured or remanufactured after January 1st, 2001 are equipped with "Emission Critical Components". These components have been identified as being critical in enabling the locomotives to be operated in compliance with EPA emissions requirements. Accordingly, for our various warranties and representations regarding emissions compliance for these locomotives to remain in force and effect, replacement and repair of Emission Critical Components should be done only in accordance with the most recent compliant engine parts list published by our engineering group.

Screen 12:
Engine Maintenance to Ensure EPA Compliance:
Failure to install compliant parts and/or parts meeting required engineering specifications may even result in serious mechanical failures and may void our mechanical and emissions defect warranties for the locomotives. By law, beginning January 1, 2001, the owners of these locomotives are required to ensure that all scheduled or required emissions-related maintenance is performed on a timely basis and that all emissions-related repairs and maintenance performed on these locomotives is performed in accordance with the maintenance instructions provided by the manufacturer.

Screen 18:
Summary:
You have reached the end of this module!

In this module, you learned to:

- State the information represented by the 7FDL engine classification.
    - The letter-and-numeral code combination used to classify the 7FDL engine is based on the following:
        - ‘7’ indicates our category of mechanical devices.
        - ‘F’ represents the 9" engine cylinder bore and 10.5" piston stroke.
        - ‘D’ stands for diesel.
        - ‘L’ indicates that the engine is designed for a locomotive application.

- Describe the terms associated with the 7FDL diesel engine orientation and cylinder locations.
  - The free end of the engine faces the radiator cab. It is the end where the turbocharger and intercoolers are mounted.
  - The alternator end of the engine is the end where the generator or alternator is mounted. This end of the engine is oriented towards the operator's cab.
  - The cylinders are numbered from the free end to the alternator end of the engine.
  - The right side or left side of the engine is determined when viewing the engine while facing the generator or alternator end of the engine. The right side of the engine is on the left side of the locomotive.
  - During engine operation, the crankshaft rotates clockwise when viewed from the free end and counterclockwise when viewed from the alternator end.

- Recognize the differences in engine specifications for the 7FDL 12-cylinder and 16-cylinder engines.
  - The 7FDL 12-cylinder and 16-cylinder engines differ with respect to engine specifications, such as number of cylinders, firing order, and weight.

- Explain how 7FDL engines have evolved to meet regulatory requirements.
  - The primary focus of the EPA regulation is the reduction of nitrogen oxides or NOx. Also measured and regulated are hydrocarbons, carbon monoxide, particulate matter, and smoke.
  - To meet the Tier 0 emission standards set by the Environmental Protection Agency (EPA), modified 7FDL diesel engines were put into production on January 1st, 2001. Engines manufactured between January 1st, 2001 and December 31st, 2001 were Tier 0 compliant.
  - 7FDL diesel engines were put into production on January 1st, 2002 through 2004 to comply with the EPA Tier 1 regulations. Going from Tier 0 to Tier 1 represents a 22% reduction in NOx and a 25% reduction in particulate matter.
  - In 2008, the emission standards were modified and the revised Tier 0 and Tier 1 were designated as Tier 0+ and Tier 1+. These revised guidelines are applicable to 7FDL engines that were originally produced between 1993 and 2004, but are remanufactured as of January 1st, 2010.
  - There are currently two different versions of Part 1033-compliant 7FDL diesel engines - the Tier 0+ and the Tier 1+ compliant engines. Differences between the two versions of diesel engines are that Tier 0+ versions maintain the Tier 0 camshaft assemblies and turbochargers.
  - There are some Emission Critical Components in the engine that are critical to ensuring compliance with EPA standards. Customers must follow our guidelines for maintenance, repair, and replacement of these components to ensure EPA compliance. Validity of our warranties is also dependent on following these guidelines.

<u>Major Components</u>

Screen 1:
<u>Introduction to 7FDL Diesel Engine Components:</u>
Welcome to the Major Components module of the 7FDL Diesel Engine Basic course. The 7FDL engine is a high-compression, four-stroke, medium-speed engine designed specifically for locomotive service. A high-capacity turbocharger, efficient combustion system, and electronic fuel injection combine to provide a fuel efficient engine that meets strict emissions levels.

At the end of this module, you will be able to:

- Identify the major components in a 7FDL diesel engine.
- State the purpose and location of the major components in the 7FDL engine.

Screen 2:
<u>Engine Mainframe:</u>
The engine mainframe is a large iron casting, sometimes referred to as the engine block, which provides a base to attach all the other engine components. Oil passages are cast into the frame to reduce the potential for leaks. No cooling water, intake air, or exhaust gases come in direct contact with the mainframe.

Screen 3:
<u>Fuel System:</u>
The purpose of the fuel system is to deliver high-pressure diesel fuel to the combustion chamber. The fuel system has three components: the high-pressure fuel pump, the high-pressure fuel line, and the fuel injection nozzle.

Screen 4:
<u>Turbocharger:</u>
The turbocharger is an exhaust-driven air compressor. It provides compressed air to support more complete combustion of the fuel. The turbocharger is driven only by exhaust gases for the entire speed range, and is not run by any belts or gear trains. The turbocharger is mounted to the free end of the engine.

Screen 5:
<u>Exhaust Manifolds:</u>
The exhaust manifolds channel the exhaust gases from the cylinders to drive the turbocharger. They are located in the vee of the engine.

Screen 6:
<u>Engine Crankshaft:</u>
The engine crankshaft, which runs through the center of the mainframe, converts the linear motion of the pistons into radial motion to drive the alternator. For the 12- and 16-cylinder 7FDL diesel engines, there are 7 and 9 main bearing journals, respectively, to anchor the crankshaft to the mainframe. The crankshaft and the bearing journal surfaces are nitride hardened to provide longer component life. The crankshaft main bearings are designed to minimize the friction at the points where the crankshaft is anchored to the mainframe. They also provide a base to control the oil film on which the crankshaft rides.

Screen 7:
Vibration Damper:
The vibration damper reduces the shock of the combustion stroke. Without the damper, the crankshaft would break. The damper is located at the free end of the crankshaft, and is made up of a flywheel inside a housing.

Screen 8:
Split Gear:
The split gear drives the camshaft gears. It is assembled onto the crankshaft in two pieces at the alternator end of the crankshaft.

Screen 9:
Rubber-Bonded Drive Coupling:
The rubber-bonded drive coupling provides the interface between the crankshaft and the auxiliary drive gear. The auxiliary drive gear is bolted to the outside ring of the rubber-bonded drive coupling, and drives an idler gear. The idler gear, in turn, drives the water and lubricating oil pumps. In the event that the gear driven oil or water pumps seize or lock up, the rubber bond drive will shear, thus disconnecting the auxiliary drive gear from the crankshaft. This feature is designed to provide crankshaft protection.

Screen 10:
Camshaft:
The camshaft is gear-driven off the crankshaft. Lobes on the camshaft provide the motion to open the intake and exhaust valves and operate the high-pressure fuel pumps.

Screen 11:
Connecting Rod Arrangement:
Each connecting rod arrangement includes two rods, the master rod and the articulating rod. The master rod is installed in the left bank of the engine. The articulating rod, linked to a master rod by a pin connection, is located in the right bank of the engine.

Screen 12:
Steel Crown Piston:
The piston is a critical component in the diesel engine. It compresses air for combustion and transfers the energy produced from combustion to the crankshaft via the connecting rod. The piston is a two piece assembly, consisting of the piston crown and the piston skirt, that is housed within the cylinder assembly. The top or crown of the piston is steel for high strength and resistance. The bottom or skirt of the piston is aluminum for light weight. It houses the piston pin for the connection between the piston and the connecting rod.

Screen 13:
Cylinder Assembly:
The purpose of the cylinder assembly is to contain and control the expansion of gases from combustion. The unitized cylinder is made up of three major components: the cylinder jacket, the cylinder liner, and the cylinder head. The cylinder jacket is the outside casting that houses all the other cylinder components. The cylinder liner is a heavy-walled tube that is hardened or chrome plated for extended wear. It is one of the components that forms the combustion chamber. The cylinder liner is assembled inside the cylinder jacket. The cylinder head is welded to the top of the

cylinder liner to form the top of the combustion chamber. The intake and exhaust valve guides are assembled to the cylinder head. The valve seats are provided through welding and angle grinding in the cylinder head intake and exhaust ports.

Screen 19:
Summary:
You have reached the end of this module!

In this module, you learned to:

- Identify the major components in a 7FDL diesel engine.
  - The major components of a 7FDL engine are
    - Engine mainframe
    - Engine crankshaft
    - Vibration damper
    - Rubber-bonded drive coupling
    - Fuel system
    - Split gear
    - Engine main bearings
    - Connecting rod arrangement
    - Steel crown piston
    - Engine camshaft
    - Turbocharger
    - Exhaust manifolds
    - Cylinder assembly

- State the purpose and function of the major components in the 7FDL engine.
  - The engine mainframe provides the base to attach all other engine components.
  - The engine crankshaft converts the linear motion of the pistons into a radial motion to drive the alternator. It runs through the center of the mainframe.
  - The vibration damper reduces the shock of the combustion stroke. It is located at the free end of the crankshaft.
  - The rubber-bonded drive coupling provides the interface between the crankshaft and the auxiliary drive gear.
  - The fuel system delivers high-pressure diesel fuel to the combustion chamber.
  - The split gear drives the camshaft gears. It is assembled onto the crankshaft in two pieces at the alternator end of the crankshaft.
  - The crankshaft main bearings minimize the friction at the points where the crankshaft is anchored to the mainframe and also provide a base to control the oil film on which the crankshaft rides.
  - Each connecting rod includes two rods: the master rod and the articulating rod. The master rod is installed in the left bank of the engine and the articulating rod is installed in the right bank of the engine.
  - The piston compresses the air for combustion and transfers the energy produced from combustion to the crankshaft via the connecting rod.
  - The lobes on the camshaft provide the motion to open the intake and exhaust valves and the high-pressure fuel pumps.
  - The turbocharger provides compressed air to support more complete combustion of the

fuel. It is mounted on the free end of the engine.

- The exhaust manifolds channel the exhaust gases from the cylinders to drive the turbocharger. They are located in the vee of the engine.
- The cylinder assembly contains and controls the expansion of gases from combustion.

Internal Subsystems

Screen 1:
Introduction to Internal Subsystems:
Welcome to the Internal Subsystems module of the 7FDL Diesel Engine Basic course. This module describes the flow paths that water, fuel, combustion air, exhaust air, and lubricating oil take through the 7FDL™ diesel engine.

At the end of this module, you will be able to:

- Define the purpose of each of the internal subsystems within the 7FDL diesel engine.
- Explain the flow of lubricating oil, cooling water, fuel, combustion air, and exhaust air in the 7FDL diesel engine.

Screen 2:
Lubricating Oil Path:
The purpose of the lubricating oil system is to supply pressurized lubricating oil to the moving parts of the engine and to carry away heat produced by friction. The lubricating oil has two distinct flow paths for supplying oil to the internal diesel engine components, with one path directing lubricating oil to the crankshaft main bearings and the other path directing lubricating oil to four of the camshaft bearings. From the lubricating oil filter tank, lube oil passes through the Integrated Front End (IFE) cover on the free-end of the engine to the main oil header. Branch passages within the main frame then direct oil to each of the two internal flow paths.

Screen 3:
Lubricating Oil Path (Cont'd):
In the first oil flow path, internal drilled passageways in the main frame carry the oil from the main oil header to each main bearing location, thus supplying oil to all of the crankshaft main bearings. Oil enters the crankshaft from the main bearings and flows through diagonally drilled holes in the crankshaft to the crankpins and rod bearings. The oil passes from the rod bearings through the master rods to the articulated pins and bushings. Oil then flows through drilled passages in the master and articulated rods to lubricate the piston pins and bushings. From each piston pin, oil passes through the piston skirt to the chamber under the piston crown to carry away heat from the piston crown. Oil then flows out of the piston crown through an orifice and gravity drains back into the crankcase.

Screen 4:
Lubricating Oil Path (Cont'd):
In the second oil flow path, internal drilled passageways in the main frame carry the oil from the main oil header to the number 2 and number 8 cam bearing locations on both sides of the 16-cylinder engine. The oil entering the four camshaft bearings then travels lengthwise through the camshaft sections. Radial holes in the shaft sections supply oil to each of the other camshaft bearings. The camshaft bearings contain annular grooves connecting to passages in the engine main frame, from where the oil flows to the valve and fuel crosshead guides. The oil passage to the right number 7 and 8 (R7/8) camshaft bearings also supplies oil to the oil gauges and sensors. The oil then passes through the crosshead guides and into the crossheads, then up through the hollow push rods to oil the rocker and valve train assemblies to the tops of the cylinders. The oil gravity drains back down around the push rods and over the crosshead rollers and cam lobes before

draining back into the crankcase.

Screen 5:
Lubricating Oil Path (Cont'd):
In addition to the two oil flow paths to the internal engine components, lubricating oil is also supplied to the auxiliary drive gear end, barring-over gearbox, and the free-end components. The auxiliary drive gear is lubricated internally by oil flowing from a passage within the crankshaft through the gear hub. Oil passes through the bearings and returns by gravity to the crankcase. Lubricating oil is supplied to the barring-over gearbox by an internal drilled passageway in the main frame to the gearbox. The oil from the gearbox returns to the crankcase internally. The free-end bearing is lubricated through a passage from the engine oil header to an annular groove around the bearing. Another passage connects the annular bearing groove to a passage in the idler gear shaft to lubricate its bushing. The camshaft and split drive gears are splash lubricated through an orifice and pipe from the engine oil header. The bearings and drive gears of the lubricating oil and water pumps are lubricated by running partially submerged in oil in the free-end cover reservoir.

Screen 6:
Cooling Water Path:
The purpose of the cooling water system is to maintain the operating temperature of the engine under all throttle calls and load conditions. Water flows from the water pump into the front end cover of the engine. Passing through the front end cover, the water then enters the inlet water headers where it is supplied to each of the cylinders. Within each cylinder, water flows through an opening in the cylinder jacket wall and is forced from the lower band of the cylinder liner through drilled passageways to the upper band of the cylinder liner. Cooling water from the top of the cylinder liner then flows to cavities in the cylinder's head. After cooling the head, the water passes through an outlet opening in the top of the head and a core passage in the top portion of the cylinder jacket to the water discharge header.

Screen 7:
Fuel Oil Path:
The purpose of the fuel oil system is to provide fuel to the cylinders for combustion and to provide cooling for the high-pressure fuel equipment. Fuel oil is supplied through parallel low-pressure fuel lines to the inlets of each high-pressure fuel pump. The pumps, driven by the camshafts, pressurize the fuel to over 18,000 psi. A solenoid, located on each high-pressure pump, is electronically controlled to open and close based on control signals from the Electronic Fuel Injection (EFI) computer. When the solenoid is open, pressurized fuel oil is fed to the fuel injector through the high-pressure fuel line. At a preset pressure, the fuel is sprayed into the combustion chamber where it combines with compressed air and ignites, causing combustion to occur. Fuel that is not used for combustion cools the high-pressure fuel components and then returns to the fuel tank through low-pressure return lines. Low-pressure fuel paths also exist to lubricate the internal parts of each high-pressure pump and to prevent excess fuel system pressure from damaging the high-pressure pumps.

Screen 8:
Combustion Air Path:
The purpose of the combustion air system is to supply compressed air to the power assembly for combustion. At low speeds, the engine draws air through the turbocharger. At high speeds and

increased loads, the energy produced by the hot exhaust gases drives the turbocharger's turbine, rotating the compressor. The heated air, up to as much as 350°F (177°C) at Notch 8, passes through the intercooler cores. These heat exchangers can cool the intake air to as low as 145°F (63°C). At idle or at light loads in cold weather, the air may actually be warmed by heat transferred from the water in the intercooler cores. From each intercooler, the air runs through an air manifold to the power assemblies. Within each power assembly, the air is supplied to the combustion chamber when the corresponding intake air valves are open.

Screen 9:
Exhaust Air Path:
The purpose of the dual-pipe exhaust manifold is to channel the exhaust gases from the combustion chambers to the turbocharger to supply the energy needed to compress the combustion air. As the exhaust valves open, the exhaust gases exit into the exhaust manifold. The pressure created by the hot exhaust gases turns the turbine in the turbocharger. Then the exhaust gases exit to the atmosphere through the muffler assembly.

Screen 14:
Summary:
You have reached the end of this module!

In this module, you learned to:

- Define the purpose of each of the internal subsystems within the 7FDL engine.
    - The lubricating oil system supplies pressurized lubricating oil to the moving parts of the engine.
    - The cooling water system maintains the operating temperature of the engine under all throttle calls and load conditions.
    - The fuel oil system delivers fuel to the cylinders for combustion and provides cooling to the high-pressure fuel equipment.
    - The combustion air system supplies compressed air to the power assembly for combustion.
    - The exhaust air system channels the exhaust gases from the combustion chamber to the turbocharger to supply the energy needed to compress the combustion air.

- Explain the flow of lubricating oil, cooling water, fuel, combustion air, and exhaust air in the 7FDL diesel engine.
    - Lubricating Oil Path
        - The lubricating oil has two distinct flow paths.
        - In the first oil flow path, internal drilled passageways in the main frame carry the oil from the main oil header to each main bearing location, thus supplying oil to all of the crankshaft main bearings. Through diagonally drilled holes in the crankshaft, oil flows to the crankpins and rod bearings. The oil passes from the rod bearings through the master rods to the articulated pins and bushings. Through drilled passages in the master and articulated rods, oil flows to the piston assembly and lubricates it. The oil is then drained back into the crankcase by gravity.
        - In the second oil flow path, internal drilled passageways in the main frame carry the oil from the main oil header to the number 2 and number 8 cam bearing locations on

both sides of the 16-cylinder engine. The oil entering the four camshaft bearings then travels lengthwise through the camshaft sections. The camshaft bearings contain annular grooves connecting to passages in the engine main frame, from where the oil flows to the valve and fuel crosshead guides and crossheads. The oil then flows up through the hollow push rods to oil the rocker and valve train assemblies. The oil drains back down around the push rods and over the crosshead rollers and cam lobes before draining back into the crankcase. The oil passage to the right number 7 and 8 camshaft bearings also supplies oil to the oil gauges and sensors.

    - In addition to the two oil flow paths to the internal engine components, lubricating oil is also supplied to the auxiliary drive gear end, barring-over gearbox, and free-end components.
- Cooling Water Path
    - Passing through the water pump and the front end cover of the engine, cooling water enters the inlet water headers. From the inlet headers, cooling water is supplied to an opening in the cylinder jacket wall of each cylinder, from where it passes to and cools the lower and upper bands of the cylinder liner. Cooling water from the top of the cylinder liner then flows to cavities in the cylinder's head. After cooling the head, the water passes to the water discharge header.
- Fuel Oil Path
    - The fuel flows to the inlets of the high-pressure fuel pump, where the fuel is pressurized and fed to the fuel injectors. At a predetermined pressure, the fuel is sprayed into the combustion chamber where it combines with compressed air and ignites, causing combustion to occur. Fuel that is not used for combustion cools the high-pressure fuel components and then returns to the fuel tank through low-pressure return lines.
- Combustion Air Path
    - To provide air for combustion, at low speeds, the engine draws air through the turbocharger. At high speeds and increased loads, the energy produced by the hot exhaust gases drives the turbocharger. The heated air passes through the intercooler cores and runs through an air manifold to the power assemblies, where the air is supplied to the combustion chamber when the intake air valves are open.
- Exhaust Air Path
    - The exhaust gases exit into the dual-pipe exhaust manifold. The pressure created by the hot exhaust gases turns the turbine in the turbocharger. Then the exhaust gases exit to the atmosphere through the muffler assembly.

Electronic Fuel Injection

Screen 1:

Introduction to Electronic Fuel Injection System:

Welcome to the Electronic Fuel Injection module of the 7FDL Diesel Engine Basic course. This module describes the function and major components of the Electronic Fuel Injection or EFI system of the 7FDL Diesel Engine.

At the end of this module, you will be able to:

- Define the purpose of the EFI system.
- State the purpose and location of each EFI system major component.
- State the purpose and location of each EFI system instrumentation device.
- Describe how the EFI system works.

Screen 2:

Purpose of the EFI System:

In the 7FDL diesel engine, the EFI system is an important design feature that reduces emissions and creates a more fuel-efficient engine. The primary purpose of the EFI system is to deliver an appropriate amount of fuel, at the correct time, to each of the cylinders of the diesel engine. The secondary purpose of the EFI system is to monitor and identify certain engine operating parameters and provide engine protection capabilities. In addition to fuel efficiency and reduced emissions, the EFI system also provides improved diagnostic capabilities.

Screen 3:

Purpose of the EFI System (Cont'd):

The EFI system monitors and identifies certain operating parameters and, if those parameters are detected as being outside normal limits, will alert the microcomputer system to reduce engine speed and/or alternator load and excitation. Sensors within the EFI system send the information related to the engine's operating conditions to the Smart Displays. The difference between the EFI system and a mechanical fuel system is the ability of the EFI system to control fuel delivery timing. A solenoid, which receives electrical signals from the EFI computer, can tightly control fuel delivery timing.

Screen 4:

The EFI Controller:

The EFI system consists of four major subgroups. They are the EFI controller, the diesel engine speed sensors and top dead center probe, system sensors, and mechanical components. The EFI controller is the microprocessor that controls the EFI system. The EFI controller is a part of the Electronic Governing Unit or EGU. The primary function of the EGU is to control engine speed by controlling the high-pressure fuel pump solenoid located on each cylinder assembly. Through the control of the solenoids, the EGU can vary the fuel timing and the amount of fuel delivered to each cylinder. Along with controlling engine speed, the EGU performs some other important functions. Several inputs are sent to the EGU from sensors on the locomotive.

Screen 7:

Diesel Engine Speed Sensors and Top Dead Center Probe:

In order to calculate the correct fuel delivery timing, the EFI controller must know two things - engine position in relation to rotational position on the left cam and the engine speed (RPM). This information is gathered by the top dead center probe, also known as the engine position sensor (EPS) and the diesel engine speed sensors, also known as the number 1 and number 2 crankshaft speed sensors (CNK1 and CNK2).

Screen 8:
Diesel Engine Speed Sensors and Top Dead Center Probe (Cont'd):
The engine position sensor, located on the left cam gear cover, is a magnetic pickup that sends pulses to the EGU. The EGU uses this information to determine the rotational position of the engine. The crankshaft speed sensors are magnetic pickups that detect engine speed by means of a tone ring located at the alternator end of the split gear on the crankshaft. The speed sensors are located at one of two possible locations on the 7FDL engine: either on a bracket inside the crankcase at the alternator end of the engine reading off a tone ring on the split gear, or outside the crankcase on the left alternator end of the engine reading off a timing ring assembled to the crankshaft. Note that only one of the two speed sensors is required to run the engine; the second sensor is a backup in case of a sensor failure.

Screen 11:
System Sensors:
System sensors send valuable information to the EGU. There are two types of system sensors – fuel management sensors and engine protection sensors. The inputs from the fuel management sensors are used to calculate the correct air-to-fuel ratio and set fuel limits for the cylinders. The EGU uses information supplied from the air intake manifold sensors to do this. The inputs from the engine protection sensors are used to provide engine protection. The EGU does this by monitoring certain engine support parameters. The sensor box, which holds the fuel management and engine protection sensors, is located at the left side alternator end of the engine. The system sensors include the fuel injection manifold air pressure (FIMAP) sensor, the fuel injection manifold air temperature (FIMAT) sensor, the fuel injection oil pressure (FIOP1) sensor, the fuel injection water pressure sensor (FIWPS), and the fuel injection engine water temperature (FIEWT) sensor.

Screen 12:
FIMAP Sensor:
The FIMAP takes a pressure tap off the air intake manifold located at the left 8-cylinder location. The pressure tap feeds into a sensor box located next to the L8 cylinder. Inside the sensor box, a transducer supplies information to the EGU.

Screen 13:
FIMAT Sensor:
The FIMAT is a thermistor that is used to sense the air temperature in the air intake manifold. The EGU uses this air temperature information and the pressure reading information to calculate the density of the air supplied to the cylinders for combustion. It is located in the sensor box next to the L8 cylinder location.

Screen 14:
FIOP1 Sensor:
The FIOP1 sensor supplies lubricating oil pressure information to the EGU. This information is used to protect the engine from serious damage resulting from low oil pressure. If the EGU receives

information that the engine's oil pressure does not support the throttle and load call, it will adjust the engines speed to match the present oil pressures. If the minimum pressure is not present to run the diesel engine, the EGU will shut down the engine.

Screen 15:
FIWPS Sensor:
The FIWPS sensor supplies engine cooling water pressure to the EGU. This information is used to protect the engine from serious damage resulting from low water pressure. If the EGU receives information that the engine's water pressure does not support the throttle and load call, it will adjust the engines speed to match the current water pressure.

Screen 16:
FIEWT Sensor:
The FIEWT sensor provides engine water temperature information to the EGU. The EGU uses the water sensor information to determine the right fuel-to-air ratio when the engine is cold.

Screen 17:
Mechanical Components:
The purpose of the mechanical components is to deliver the correct amount of fuel to each cylinder for combustion. Each cylinder on the 7FDL diesel engine is equipped with a high pressure fuel pump, a high-pressure fuel line, and an injector. The injector works as a check valve releasing fuel into the combustion chamber when the required pressure is reached.

Screen 18:
High-Pressure Fuel Pump:
The high-pressure fuel pump is a solenoid controlled booster pump. The pump receives a steady supply of fuel from the locomotive's low-pressure fuel system. The low-pressure fuel (90 psi) is boosted by the high-pressure pump to very high pressures (18,000 psi). The signals from the EGU control the closing point of the solenoid, thus providing the means to vary fuel timing. The EGU signals also control the duration for which the solenoid is opened, thus controlling the amount of fuel delivered.

Screen 19:
High-Pressure Fuel Line:
The high-pressure fuel line connects the high-pressure fuel pump to the injector. It transfers fuel from the pump to the injector.

Screen 20:
Injector:
The injector receives the high-pressure fuel from the high-pressure fuel pump. After the fuel in the injector reaches a predetermined pressure, the fuel will be injected directly into the combustion chamber.

Screen 24:
Summary:
You have reached the end of this module!

In this module, you learned to:

- Define the purpose of the EFI system.
  - The primary purpose of the EFI system is to deliver an appropriate amount of fuel, at the correct time, to each of the cylinders of the diesel engine.
  - The secondary purpose of the EFI system is to monitor and identify the operating parameters and provide engine protection capabilities.

- State the purpose and location of each EFI system major component.
  - The EFI system consists of four major subgroups:
    - The EFI controller is the microprocessor that controls the EFI system. The EFI controller is a part of the EGU. The main function of the EGU is to control engine speed by controlling the high-pressure fuel pump solenoid located on each cylinder assembly. Through the control of the solenoids, the EGU varies the fuel timing and the amount of fuel delivered to each cylinder. The EGU is located in the aux cab.
    - The purpose of the diesel engine speed sensor and the top dead center probe is to provide information to the EGU to determine the engine position in relation to rotational position on the left cam and the engine speed (RPM). The speed sensors are located at one of two possible locations on the 7FDL engine: either on a bracket inside the crankcase at the alternator end of the engine, or outside the crankcase on the left alternator end of the engine. The engine position sensor is located on the left cam gear cover.
    - The purpose of the system sensors is to calculate the correct air-to-fuel ratio and set fuel limits for the cylinders and to provide engine protection by monitoring certain engine support parameters.
    - The purpose of the mechanical components is to deliver the correct amount of fuel to the cylinders for combustion. The mechanical components include a high-pressure fuel pump, a high-pressure fuel line and an injector. The high-pressure fuel pump is mounted to the cylinder strongback. The injector is mounted to the cylinder head. The fuel lines connect the two components.

- State the purpose and location of each EFI system instrumentation device.
  - There are two types of system sensors:
    - Fuel Management sensors
      - The FIMAP takes a pressure tap off the air intake manifold located at the left 8-cylinder location. The pressure tap feeds into a sensor box located next to the L8 cylinder.
      - The FIMAT is a thermistor that is used to sense the air temperature in the air intake manifold. The EGU uses this air temperature information and the pressure reading information to calculate the density of the air supplied to the cylinders for combustion. It is located in the sensor box next to the L8 cylinder location.
    - Engine Protection sensors
      - The FIOP1 sensor supplies lubricating oil pressure information to the EGU. This information is used to protect the engine from serious damage resulting from low oil pressure.

        - The FIWPS sensor supplies engine cooling water pressure to the EGU. This information is used to protect the engine from serious damage resulting from low water pressure.
        - The FIEWT sensor provides engine water temperature information to the EGU. The EGU uses the water sensor information to determine the right fuel-to-air ratio when the engine is cold.
    - These sensors are located in a sensor box at the left side alternator end of the engine.

- Describe how the EFI system works.
    - Fuel, from the low-pressure fuel system, flows into the high-pressure fuel pump, and is released into the combustion chamber after passing through the high-pressure fuel line and injector.
    - The EGU controls the high-pressure fuel solenoids located on each cylinder assembly to vary the fuel timing and the amount of fuel delivered to each cylinder.
    - The engine position sensors provide information to the EGU to determine the rotational position of the engine. The crank sensors 1 and 2 provide information to the EGU about engine speed. The EGU uses this information to calculate the correct fuel delivery timing.
    - The fuel management sensors, FIMAP and FIMAT, provide information to the EGU to calculate the density of air supplied for combustion, determine the air-to-fuel ratio, and thus control the amount of fuel delivered to the combustion chamber.
    - The engine protection sensors, FIOP1, FIWPS, and FIEWT, provide diagnostic information to the EGU for engine protection.