Introduction To EGR
Exhaust Gas Recirculation
Introduction to EGR

• Why EGR?
• How EGR Reduces NOx
• Effects of EGR on Engine Operation.
• Cummins Approach to EGR
Why Exhaust Gas Recirculation

- **Basic Science**
  - NOx (Oxides of Nitrogen) pollution occurs due to high cylinder temperatures during the combustion event.
  - Air is composed of nitrogen and oxygen, and when it is heated they react to form NOx.
  - To reduce the NOx pollutants we must bring down the maximum temperatures in the cylinder during the combustion process.
Why Exhaust Gas Recirculation

• Methods used to reduce cylinder temperatures.
  – Intake Air Aftercooling
    • Jacket Water Aftercooling
    • Charge Air Cooling.
  – Retarding Injection Timing.

• By the late 1990’s, a combination of both these methods reduced the NOx to 4 grams per brake horsepower hour.
Why Exhaust Gas Recirculation

• New Standards.
  – October 2002 Consent Decree
    • NOx & NMHC combined cannot exceed 2.5 g/bhp-hr.
    • Cooled intake air and/or retarded injection timing alone are not capable of reaching this reduction in NOx.
    • The next technical step in reducing peak combustion temperatures is to use cooled exhaust gas recirculation (EGR).
Why Cooled EGR?

• Extensive research into options. EGR the best in terms of:
  – emissions
  – cost
  – reliability
  – within existing technology

• Common across all automotive engine platforms in 2005
  – transition to new technology began in first quarter 2002
Cooled Exhaust Gas Recirculation

• What is cooled Exhaust Gas Recirculation.
  – Cooled EGR is where a portion of the exhaust gas is routed through a cooler, then the cooled exhaust gases are reintroduced into the fresh charge air.
  – This mixture contains fewer oxygen molecules per volume of charge, which reduces the flame temperature during combustion, thus reducing emissions.
How EGR Reduces NOx

• Exhaust Gas Recirculation reduces NOx by,
  – Taking some exhaust gas from the exhaust manifold, circulates it through a cooler, then mixes it with fresh air then the mixture enters the combustion chamber.
  – During the combustion process, the inert cooled exhaust gas absorbs some of the heat energy generated during combustion thus lowering the peak combustion temperature.
How EGR Reduces NOx
How EGR Effects Horsepower

• To maintain the same power level as a non-EGR engine, the combustion process of the EGR engine must contain the same amount of oxygen molecules.

• Since the EGR engine maintains the same amount of Oxygen and adds inert exhaust gas, the total amount of gas in the combustion chamber increases. This will cause higher peak pressures in the cylinder but will produce the same power.
Cylinder Pressure

Peak Cylinder Pressures

With EGR

Without EGR

Crank Angle (degrees)

Cylinder Pressure (psi)
EGR Design Elements

• There are five design elements that are absolutely critical in applying EGR.
  – High peak cylinder pressure
    • Increased volume of gas entering the cylinder.
  – Higher injection pressure.
    • To atomize fuel entering the cylinder. This causes a more complete burn in the lower temperature cylinder.
  – Higher turbocharger compressor capability
    • To keep engine power up with EGR.
  – Flexible intake and exhaust pressure control.
    • To make the EGR flow into the engine without a loss in fuel economy.
  – Engine must have higher heat rejection to cooling system.
    • To cool the EGR.
Increased Heat Rejection to Coolant

Non-EGR
- Exhaust Energy: 33%
- Work: 44%
- Heat Rejection: 23%

EGR
- Exhaust Energy: 26%
- Work: 44%
- Heat Rejection: 23%

7% Additional Heat Rejection
Engine Performance

• The 2002 Dodge ISB engine at 2.0 g/bhp-hr.
  – 2% better fuel economy.
  – Better transient response.
  – Better clutch engagement torque.
  – Better cold starting.

• No significant change in engine performance of other 2002 models over previous engines.

• All engine have more than a 50% reduction in NOx.
1) Exhaust Pressure inside the Exhaust Manifold is increased by closing the Variable Geometry turbo mechanism.
2) This increased Exhaust Manifold Pressure causes exhaust gas to flow through the EGR control valve when opened.
3) The exhaust gas flows through the cooler.
4) The exhaust gas exits the cooler and flows through the exhaust transfer tubing to the intake side of the engine.
5) Exhaust gas enters a mixer and is combined with intake air just before entering the intake manifold.
EGR System Components

• Variable Geometry Turbo
• Exhaust Gas Recirculation (EGR) Valve
• Exhaust Gas Recirculation (EGR) Cooler
• Exhaust Transfer Tubing
• Intake Mixing Device
2002 Air Handling Components
(typical arrangement ISX)

- VG Turbo Water Return
- VG Turbo Water Supply
- VG Turbo Oil Drain
- VG Turbo Actuator
- EGR Cooler Water Return
- EGR Valve
- EGR Valve Water Supply
- EGR Valve Water Return
- VG Controller
- Alternator Heat Shield
- VG Turbo Oil Drain
- VG Turbo Water Return
- Air Filter and Shut-Off-Valve for VG Controller
Variable Geometry Turbocharger (VGT)

- The VG Turbo has two primary purposes:
  - The VG turbo is used to increase the exhaust manifold backpressure. This increased backpressure is used to create exhaust gas flow through the EGR system.
  - The VGT also works to build boost pressure more quickly to improve transient response.
- All variable geometry turbos use water cooled bearing housings in addition to oil lubrication.
- The VGT can also be used to provide engine braking.
Variable Geometry Turbocharger

• All Cummins VG Turbos will use a sliding nozzle to vary turbine volute exit area.

• The sliding nozzle can be actuated by a pneumatic actuator attached to the vehicle air system or by an electric motor depending on the engine platform.
  – The pneumatic actuator will be controlled by a control valve that will regulate the air pressure to the actuator.
  – The electric actuator will receive a signal from the ECM and an electric motor will move the sliding nozzle. The electric actuator contains a position sensor that will provide feedback for VG position.
Pneumatic VGT Control

ISX
Electronic VGT Control

ISB
Variable Geometry Turbocharger

(pneumatic actuator shown)

Turbine

Compressor

Speed Sensor

Fresh Air

Nozzle Ring

Yoke Mechanism

Shroud Plate

VG Actuation
(either pneumatic or electric)

Cummins West Training Center
VGT Operating Principle

Nozzle ring fully closed
Minimum  turbine volute exit area
Maximum  exhaust manifold pressure
Maximum  shaft speed
Maximum  turbo boost

Nozzle ring fully open
Maximum  turbine volute exit area
Minimum  exhaust manifold pressure
Minimum  shaft speed
Minimum  turbo boost

Nozzle position is infinitely variable between open and closed by using either a pneumatic or electrical actuator.
Exhaust Gas Recirculation (EGR) Valve

• The EGR valve regulates the amount of exhaust gas recirculated to the intake system.
• Common EGR valve approach for all engine platforms.
  – The valve is an outwardly-opening poppet valve that opens into the exhaust manifold.
  – The valve is controlled by a high speed electric motor with a gear reduction system.
  – EGR valves are sized accordingly to engine displacement.
• Valve location may vary depending on engine family.
• The motor and position sensor are protected by a heat shield and a water-cooled actuator housing.
EGR Valve
EGR Valve Internal Components

- Gear reduction.
- Motor Gear - mates with gear reduction
- Sector Gear
- Shaft for sector gear and position sensor
- Return spring to close valve if failure occurs
- Coolant passage for valve guide
- Flow of Exhaust Gas
- Poppet Valve
EGR Valve External Components

- Motor
- Heat Shield
- Position Sensor
- Coolant Port
- Exhaust Gas Inlet
- Actuator cover
- Exhaust Gas Outlet
Exhaust Transfer Tubes

- The exhaust transfer tubes are used to connect the components of the EGR system.
- Exhaust transfer tubes are used to connect the EGR valve to the EGR cooler and the EGR cooler to the air intake.
- Exhaust transfer tubes will contain a flexible section or bellows. These flexible sections are used to prevent cracking or breaking of the EGR valve, EGR cooler, and EGR plumbing due to thermal expansion.
Exhaust Transfer Tubes

This stainless steel exhaust transfer tubes deliver exhaust gas between various components of the air handling system.

Typical Midrange Arrangement

Typical Heavy Duty Arrangement
EGR Cooler

- The primary function of the EGR cooler is to reduce the temperature of the exhaust gas being recirculated into the intake system.
- Cooling the exhaust gas reduces the overall temperature of the intake air into the cylinders. By reducing the intake air temperature, the combustion event occurs at a cooler temperature.
- The exhaust gas and the water flow parallel with each other through the cooler.
- The cooler is constructed of stainless steel so it will be resistant to corrosive acids found in the recirculated exhaust gas.
EGR Cooler

Cooler is self-cleaning and will not require routine maintenance

- Coolant flows between tubes
- EGR Cooler Gas Inlet
- Exhaust Gas In
EGR Mixer

- The exhaust gas recirculation system requires a mixing device to combine the recirculated exhaust gas and the charge air from the charge air cooler. The mixer insures an equal mixture of recirculated exhaust gas and fresh charge air to all cylinders.

- Two different mixing devices may be used on Cummins engines.
  - The venturi style mixer creates a pressure drop in the venturi throat. The recirculated exhaust gas is injected into this low pressure area where mixing occurs. This type of mixer also assists in flowing more recirculated exhaust gas due to the low pressure area in the venturi.
  - The second type of mixer is a fluted style mixer. This type of mixer is used on engines that do not require the added benefit of injecting recirculated exhaust gas into a low pressure area.
Venturi Type Mixer
(ISX Shown)

- Compressed Intake Air
- Venturi Inlet
- Recirculated exhaust gas inlet
- Venturi Throat
Fluted Type Mixer
(ISB Shown)

Recirculated exhaust gas inlet
Compressed Intake Air
Controls and Diagnostics
New Sensors Required for 2002

- Turbo Compressor Inlet Temperature
- Turbo Speed Sensor
- EGR Differential Pressure Sensor
- EGR Valve Position Sensor
- EGR Cooler Outlet Temperature Sensor
- Exhaust Pressure Sensor
- VGT Position Sensor (ISB)
Turbo Compressor Inlet Temperature

- The Turbo Compressor Inlet Temperature Sensor is mounted in the compressor housing of the VG turbo.
- The sensor is used to calculate compressor outlet temperatures.
Turbo Compressor Inlet Temperature

ISX
EGR Differential Pressure Sensor

- The EGR Differential Pressure Sensor will be located on the air intake connection or in the exhaust transfer tube depending on the engine family.
- The Differential Pressure Sensor is used to measure the difference in pressure between two locations. As the flow of exhaust gas increases, the difference in the pressures increases. This EGR flow rate is then converted to determine the actual mass flow of the recirculated exhaust gas into the intake system.
Pressure Differential Sensor

ISX
Pressure Differential Sensor
Turbo Speed Sensor

- The Turbo Speed Sensor is mounted on the turbo compressor housing and is used to measure actual turbo speed.
- Turbo speed is used to protect the VG turbo from overspeed conditions.
Turbo Speed Sensor
Turbo Speed Sensor
EGR Valve Position Sensor

- The EGR Valve Position Sensor will be located on the EGR valve.
- The EGR Position Sensor measures the actual EGR valve position.
- Based on the actual feedback position, a stuck valve can be detected.
EGR Valve Position Sensor
VGT Control Position Sensor
EGR Cooler Outlet Temperature

• The EGR cooler outlet temperature sensor
• The EGR cooler outlet temperature sensor is used to measure the actual temperature of the exhaust gas exiting the EGR cooler.
EGR Cooler Outlet Temperature
EGR Cooler Outlet Temperature
Exhaust Pressure Sensor

- The exhaust pressure sensor will be mounted above the exhaust manifold. The sensor will not be mounted directly on the exhaust manifold due to the high temperatures. A stainless steel sensing line will be used to connect the exhaust pressure sensor and the exhaust manifold.
Exhaust Pressure Sensor

ISX
Exhaust Pressure Sensor
INSITE Diagnostic Tests

• VGT Override Test
  – This test will allow the user to override the VG nozzle position by commanding different VG nozzle positions and monitoring the actual position feedback.
  – Test will be used to determine if the VG nozzle is sticking, stuck in one position, or not actuating the full amount of travel.

• EGR Valve Override Test
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INSITE Diagnostic Tests

• VGT/EGR Operational Test
  – The operational test will initially start with the engine at low idle, EGR valve in the closed position, and the VGT nozzle in the open position. A turbo speed sample will be taken at these conditions.
  – The VGT nozzle will then close and a second turbo speed sample will be taken. INSITE will calculate a percent increase in engine speed.
  – If the percent increase in engine speed does not meet a predetermined specification, the test will fail and additional troubleshooting of the air handling system will be required.
VGT/EGR Operational Test

EGR / Turbocharger Operational Test

Cycles the EGR valve and/or the VGT Turbocharger through predetermined sequences to make determinations of the health of the system.

Instructions:
Please choose the component to test and select Start to begin
The vehicle air system must be fully charged to properly perform this test

Test Choices:
- EGR Valve
- Turbocharger actuator
- All

Results:

<table>
<thead>
<tr>
<th>Tested Item</th>
<th>Result</th>
<th>Units</th>
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<tbody>
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<td>EGR Valve Test</td>
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<tr>
<td>Start Turbocharger Speed</td>
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<td>rpm</td>
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<tr>
<td>End Turbocharger Speed</td>
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<td>rpm</td>
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<tr>
<td>Percent Change</td>
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<td>%</td>
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<td>VGT Actuator Test</td>
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<tr>
<td>Start Turbocharger Speed</td>
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<td>rpm</td>
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<tr>
<td>End Turbocharger Speed</td>
<td>40080</td>
<td>rpm</td>
</tr>
<tr>
<td>Percent Change</td>
<td>102</td>
<td>%</td>
</tr>
</tbody>
</table>
Air Handling Fault Code Diagnostics

- Commanded vs. Actual EGR Valve Position
- Commanded vs. Actual VG Nozzle Position
- Temperature sensor out-of-range high and low detection.
- Pressure sensor out-of-range high and low detection.
- In-range pressure sensor failure detection.
- Engine Protection Derates for:
  - High exhaust temperature
  - High turbo speed
  - High compressor outlet temperature
Questions