Demonstration of a Verification-ready, Retrofittable Dual-loop EGR System for NO_x Reduction without Aftertreatment

Task 2 Deliverable Report

for:

New Technology Research and Development Program

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Submitted by:

QuantLogic Corporation
In collaboration with: Houston Advanced Research Center

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Abstract/Executive Summary

This project will develop a technology much needed for reducing nitrogen oxide (NO_x) and particulate matter (PM) emissions from heavy-duty trucks, especially drayage trucks used in Texas ports and rail terminals. Drayage trucks are significant emissions sources for ports and rail terminals around the nation. However, the current United States Environmental Protection Agency (EPA) or California Air Resources Board (CARB) verified technologies for NO_x reduction are mostly urea selective catalytic reduction (SCR) based. The urea-SCR technologies, no matter under retrofit or first fit, are not effective for drayage cycles because they are unable to maintain SCR light-off temperature. Exhaust gas recirculation (EGR) is the most effective way to reduce engine-out NO_x emissions through reducing engine combustion temperature which contributes to lower NO_x emissions.

Traditional high pressure loop EGR method tends to increase smoke emissions especially at high engine loads. Alternative combustion modes with high EGR rates from an advanced EGR system have shown to be being more effective in NO_x reduction.

The effectiveness of advanced Dual Loop EGR system for retrofit drayage truck application has been demonstrated by the investigators in a previous New Technology Research and Development (NTRD) grant project with 50% NO_x reduction over light to medium loads under steady-state conditions without any fuel penalty.

The benefits of this proposed project include a fully developed dual loop EGR system and demonstration over the full engine speed and load range including transient conditions with a 50% NO_x reduction goal over light to medium loads for drayage truck applications. The complete dual loop EGR system will be implemented on the target vehicle for mileage accumulation and durability demonstration for future verification purpose.

Introduction / Background

Drayage trucks are significant emission sources for Texas ports. However, urea-SCR retrofit technologies are not effective for drayage cycles because they are unable to maintain SCR light-off temperature. Exhaust gas recirculation (EGR) is the most effective way to reduce engine-out NO_x emissions through reducing engine combustion temperature which attributes to high NO_x emissions. Traditional high pressure loop EGR method tends to increase smoke emissions especially at high engine loads. Alternative combustion modes with high EGR rates from an advanced EGR system have shown to be being more effective in NO_x reduction.

The effectiveness of advanced Dual Loop EGR system for retrofit drayage truck application has been demonstrated by the grantee in a previous NTRD project with 50% NO_x reduction over light to medium loads under steady-state conditions without any fuel penalty.

In the new project, the dual loop EGR system will be fully developed and demonstrated over the full engine speed and load range including transient conditions with a 50% NO_x reduction goal over light to medium loads for drayage truck applications. The complete dual loop EGR system will be implemented on the target vehicle for mileage accumulation and durability demonstration for future verification purpose.

Project Objectives / Technical Approach

The objectives for this work are to: develop a drayage truck retrofit dual-loop EGR system resulting in at least 50% NO_x reduction under light to medium load without after-treatment, and demonstrate the prototype retrofit on a drayage truck to begin accumulating hours in preparation for verification testing.

Tasks

The following seven tasks are identified in the Grant Activities (Scope of Work):

- Task 1: Procure Components,
- Task 2: Set up engine retrofit and engine control systems,
- Task 3: Steady-state engine calibration and emissions testing,
- Task 4: Transient control strategy development and testing,
- Task 5: Transient emissions tuning and testing,
- Task 6: Vehicle installation of retrofit,
- Task 7: Reporting.

The Task 2 accomplishments are summarized below.

Task 2 Set up engine retrofit and engine control systems

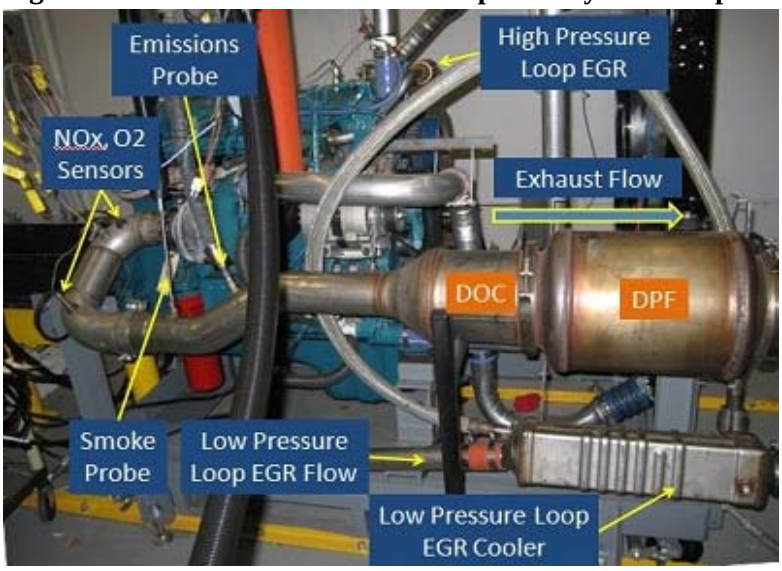
From the Grant Activities (Scope of Work):

> *Task 2 Set up engine retrofit and engine control systems*
>
> *2.2. Task Statement: The PERFORMING PARTY will set up the engine, dual loop EGR retrofit, and engine control systems in the laboratory environment in preparation for steady state testing and transient control strategy development testing.*
>
> *2.2.1. Engine and retrofit set up*
>
> *2.2.1.1. The PERFORMING PARTY will set up the test engine at the Houston Advanced Research Center's heavy-duty engine test cell and install the dual loop EGR system. The dual loop EGR system will be configured so that it can be by-passed in order to resume to stock engine configuration to obtain baseline engine emissions and performance data.*
>
> *2.2.1.2. The PERFORMING PARTY will install instrumentation for monitoring all major engine operation parameters, including: engine speed, load, intake and exhaust temperatures, intake and exhaust pressure, intake fresh air flow rate, EGR flow rates from high pressure and low pressure EGR loops, exhaust NO_x and O_2 sensors.*
>
> *2.2.2. Engine controls set up*
>
> *2.2.2.1. The PERFORMING PARTY will set up the engine control system for fueling control, dual loop EGR control, and boost control. The PERFORMING PARTY will verify and confirm control functions of those actuators and inputs from various sensors.*
>
> *2.2.3. Schedule: The PERFORMING PARTY shall complete this task within 6 months of the signed Notice to Proceed Date as issued by TCEQ.*
>
> *2.2.4. Deliverables: The PERFORMING PARTY shall submit a report to the TCEQ upon completion of this task. This report will include but is not limited to documentation, including pictures, of the installed engine, retrofit, and engine controls, as well as documentation of the verification of engine control functionality.*

The engine test cell setup, single loop and dual loop EGR systems, as well as engine control systems have been completed and verified.

The test engine was setup at the Houston Advanced Research Center's (HARC) heavy-duty engine test cell and installed with the dual loop EGR system. The dual loop EGR system is shown in Figure 1.

Figure 1 Exhaust side view of dual loop EGR system setup



The major steps for the engine setup were:

- installation of engine on the engine cart, engine cooling system, and charge air cooling system;
- connecting dyno to the engine flywheel by heavy duty driveshaft and flywheel adaptor;
- preparing rapid prototyping engine control system (open-ECU) and wireharness;
- installation of sensors (temperature, pressure and NO_x/O_2) and actuators;
- setup exhaust aftertreatment devices, the diesel oxidation catalyst (DOC) and diesel particulate filter (DPF);
- installation of EGR cooler for low pressure loop EGR; and
- installation of plumbing for high and low pressure loop EGR.

A stock engine exhaust configuration (without exhaust aftertreatment and low pressure loop EGR system) was also configured and installed on the engine to obtain baseline engine emissions and performance data. The exhaust setup for the engine baseline is shown in Figure 2.

Figure 2 Baseline engine setup with single high pressure loop EGR

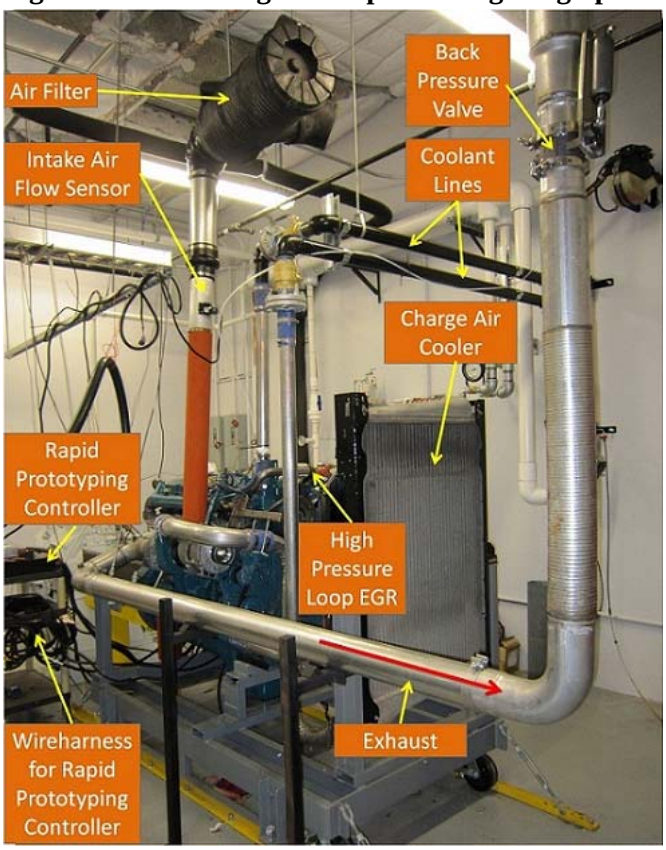
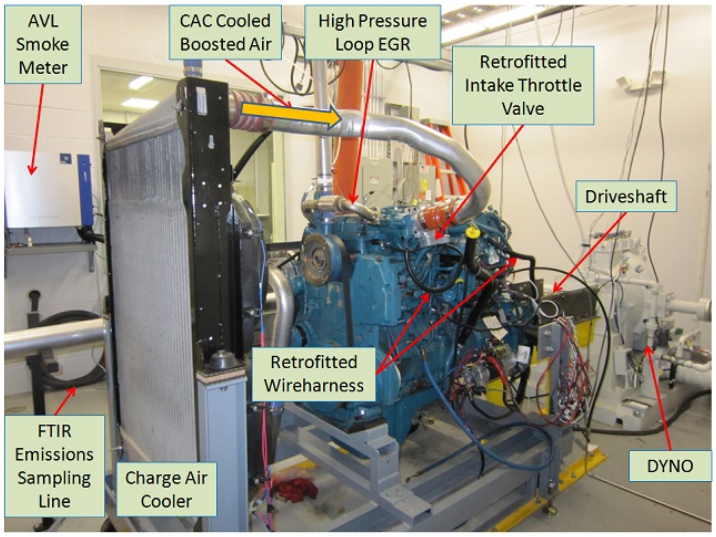


Figure 3 shows the engine setup of the intake side which consists of charge air cooler and intake throttle valve which are used for both single loop EGR system and dual loop EGR system.

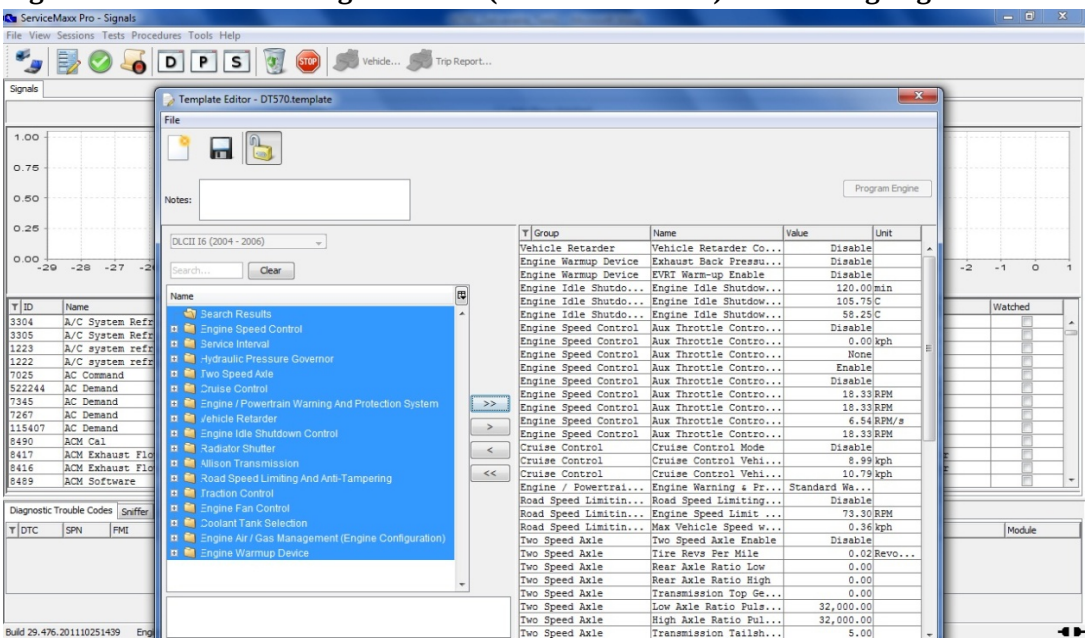
Figure 3 Intake side view of engine setup



The instrumentation for monitoring major engine operation parameters were completed, including: engine speed, load, intake and exhaust temperatures, intake and exhaust pressure, intake fresh air flow rate, EGR flow rates from high pressure and low pressure EGR loops, and exhaust NO_x and O_2 sensors.

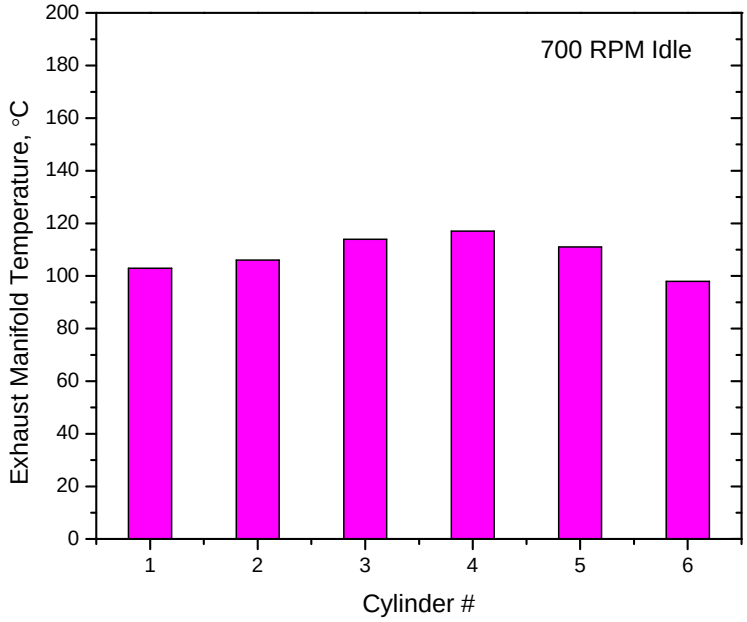
It is important and helpful to use diagnostic tools for engine control system setup to ensure that all engine sensors and actuators are functioning properly. A service tool for the International Engine diagnosis (ServiceMaxx Pro) was used to understand the engine control unit (ECU) operation status and clear the error codes in the ECU. Figure 4 shows the screen shot of the setup of the diagnosis tool used during the debugging of the engine control system setup and test run.

Figure 4 Screen shot of diagnostic tool (ServiceMaxx Pro) used during engine control setup



One important parameter used to verify if the engine is in healthy condition is the exhaust manifold temperatures. If the exhaust manifold temperatures are in a balanced distribution (higher in the middle cylinders and lower on the outside cylinders), it is a good indication that the engine is operating normally. Figure 5 shows the exhaust manifold temperature distribution at 700 revolutions per minute idle which indicated that the engine was in good condition.

Figure 5 Exhaust manifold temperature at 700 RPM idle



Discussion/Observations

Objectives vs. Results

The goal of the Task 2 is to set up the engine, dual loop EGR retrofit, and engine control systems in the laboratory environment in preparation for testing. This task should be completed within 6 months of the signed Notice to Proceed, or by December 8, 2011.

The setup of engine, dual loop EGR systems, and engine control systems tasks started early in the schedule when parts were available and completed on time (six months after the Notice to Proceed was issued). The test engine was initially run under dynamometer to verify the proper operation of the test engine, engine control, and instrumentation of sensors and actuators. All systems installed are functioning as expected.

Summary/Conclusions

The goals of the Task 2 have been accomplished. The setup of engine, dual loop EGR systems and engine control systems tasks started early in the schedule when parts were available and completed on time (six months after the Notice to Proceed was issued). The test engine was initially run under the dynamometer to verify the proper operation of the test engine, engine control, and instrumentation of sensors and actuators. All systems installed are functioning as expected.

The project is currently under Task 3: Steady-state Engine Calibration and Emissions Testing. The overall project progress is on the original planned schedule and within budget.

Acknowledgements

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