21st Century Locomotive Technology: Quarterly Technical Status Report 19 DOE/AL68284-TSR19

This is the quarterly status report for the 21st Century Locomotive Technology project, DOE Award DE-FC04-2002AL68284. This report covers activities performed July 2007 to September 2007.

Project Management

The status of the 21st Century Locomotive Technology project was reviewed with DOE HQ personnel, Lee Slezak, Gurpreet Singh, and Jules Routbort at GE Transportation facility in Erie, PA, on August 10. The DOE visitors also took the opportunity to inspect the GE Transportation diesel engine manufacturing plant in Grove City PA, to ride the GE Evolution Hybrid demonstrator locomotive, and to inspect the diesel-electric locomotive assembly plant. The project team looks forward to welcoming the DOE Project Officer to review the project at GE Global Research, Niskayuna NY on October 16.

A paper titled "Application of energy storage batteries to hybrid locomotives and mine trucks" which incorporates some work on hybrid locomotive carried out under Task 3 of this project has been submitted for presentation at EVS-23 (Electric Vehicle Symposium), Anaheim CA, December 2-5, 2007. The paper was marked by the standard DOE acknowledgement and disclaimer.

Task 1: Advanced Fuel Injection

Objective

Develop and demonstrate an advanced fuel injection scheme to minimize fuel consumption, while meeting Tier 2 emissions levels.

Progress since last report

In the third quarter of 2007, we continued engine performance testing on GE Global Research's locomotive single cylinder engine. The common rail fuel system as well as the production unit pump system were evaluated. At the beginning of the quarter we concluded the common rail nozzle geometry study we started in Q2. We down-selected from a wide range of nozzles to favorable nozzle geometries, which demonstrated the best engine performance for single injections. To reestablish a baseline and quantify the relative performance gains, the production unit pump system (UPS) was installed. The common rail fuel system was used to systematically explore pilot and post injection strategies. Our goal is a further improvement of the engine performance by implementing multiple injection strategies.

Our focus in the last quarter was on single pilot and single post injection schemes and the combination thereof. In order to find the optimum pilot injection strategy, we explored a wide range of pilot injection durations and dwell times. For post injections the injection duration and location was varied in a similar fashion as for the pilot injection. The studies were carried out for several rail pressure levels and a range of main injection advance angles. In selected cases, the multiple pilot injection cases were explored. Engine performance was quantified by SFC benefit at NO_x parity and PM emissions level.

Three are three main accomplishments in the area of advanced fuel injection over the last quarter:

1. Identified the optimum nozzle geometry (hole number and cone angle).
2. Explored single pilot injection experimental space (dwell and duration) at both medium and high load conditions for selected rail pressures.
3. Quantify PM benefits for single post injections and their effect on SFC-NO_x tradeoff.

The nozzle geometry study allowed quantifying the effects of hole number, cone angle and needle lift characteristics on the effects on engine performance. The most favorable nozzle geometries in this study suggested the hardware used for the multiple injection strategy.

1. We demonstrated that specific nozzle geometries (hole number and angle) can offer fuel benefits at NO_x-parity over our baseline nozzle with a very minor increase PM emissions. The nozzle geometry study was based on single injection performance. The optimum nozzle selection process was based on the observed SFC benefits at Tier 2 NO_x-emissions levels while meeting PM regulations. Among the geometries tested, the most favorable nozzle geometry at part load was found to be different to the most favorable one at full load. Also, performance results where strongly dependent on rail pressure. Therefore the overall optimum nozzle geometry has to be determined on a duty cycle bases.

2. The multiple injection space was explored using the optimum nozzle geometry determined from the single injection study. Based on the learning during the multiple injection study, further injector hardware changes are possible. The optimum nozzle based on single injection is used as a starting point in terms of injector hardware. For selected common rail injection pressures, we showed that the addition of pilot injections provides a SFC benefit (at constant NO_x level) over the single injection at constant rail pressure. The addition of those pilot injections was found to have little impact on PM emissions. To achieve constant NO_x level as for a single injection, the start of main injection had to slightly retarded when using pilot injections.

For single injections, the rail pressure was found to have a strong effect on SFC. For rail pressures levels leading to a higher SFC with a single injection, the SFC benefits observed for adding on a pilot injection where larger. At full load, pilot injection strategies have shown improvement for limited NO_x levels over the UPS. At part load, pilot injections improved the NO_x-SFC tradeoff compared to the UPS over a wider range of NO_x levels. During the study we used also high-speed data to determine the rate of heat release and its impact on SFC and NO_x.

3. The addition of post injections allowed for significant reduction in PM and, in selected cases at part load, simultaneous benefit in SFC. The relative reduction in PM was larger at part load than at full load. For specific load conditions, the engine performance was found to be fairly insensitive to the location of the post injection. The post injection duration was

found to have a strong impact on engine at all loads. While larger fuel quantities in the post injection decreased the PM emissions further in our study, the NO_x-SFC tradeoff turned unfavorable for prolonged post injection durations. In order to achieve NO_x parity with an additional post injection, the main injection timing had to be slightly advanced.

Planned activity for next quarter

Over the next quarter, we plan to optimize our multiple injection strategy further. The task list includes combinations of pilot and post injections and multiple pilot and multiple post injections. High-speed data, e.g. heat release traces, will be used to guide multiple pilot injection schemes and possible hardware changes. Besides the hole number and cone angle, the impact of needle lift profile will be investigated. Other multiple injection strategies to be explored or combined include split injections. Full load will remain the focus since approximately half of the total locomotive fuel consumption occurs at Notch 8.