



21st Century Locomotive Technology: Quarterly Technical Status Report 12 DOE/AL68284-TSR12

This is the quarterly status report for the 21st Century Locomotive Technology project, DOE Award DE-FC04-2002AL68284. This report covers activities performed October 2005 to December 2005.

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Task 1: Advanced Fuel Injection

Objective

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

Progress since last report

Over the last quarter, the production unit pump system (UPS) was installed on the single cylinder engine (SCE). The UPS data, which represents the production engine performance, was used to determine the performance entitlement of the high-pressure common rail (HPCR) system at notch 4 and notch 8. This UPS data collected on the SCE was also compared with recent data from a production design multi-cylinder engine (MCE) to investigate the performance similarities and differences between the two engine systems.

Experimental milestones accomplished over this quarter:

In the last quarter we focused on collecting baseline data on the SCE. The baseline configuration consists of the UPS fuel system, which is the current production fuel system design. The UPS dataset consisted of a simple swing in injection timing, with selected data repeated on different days. The UPS data served two purposes: The first purpose was to perform capping experiments which, when compared with the HPCR engine data, quantify the entitlement of the advanced fuel system on the SCE. An assessment of the HPCR system in comparison to the UPS system at notch 4 and notch 8 has been established. Secondly, the SCE data with the UPS was used in a study to explore the correlation of MCE and SCE performance. The results from this study are summarized below and also will be further documented in an ASME publication.

Review of single cylinder engine test setup:

As this is the conclusion of a family of HPCR and UPS engine data, we take this opportunity to summarize the test set-up and performance variables measured. Table 1 lists the key measurements for the engine performance metrics, the measurement devices and their measurement techniques.

Emissions and fuel consumption are compared on an indicated and brake specific basis. The accuracy of the indicated-specific basis is extremely sensitive to the in-cylinder pressure signal and top dead center phasing. This is one reason that brake specific performance variables are more commonly used. When evaluating SCE data using different fuel systems, it is not trivial to compare brake specific performance. For the UPS configuration the camshaft drives the fuel pump, while the fuel pump on the HPCR system is externally driven. To compare the UPS and the HPCR data on a brake specific basis, the estimated power to drive the common rail fuel pump is subtracted from the measured brake power. This way, the brake specific datasets represent engine systems with consistent parasitic loads and therefore can be compared. The



accuracy of the brake specific values for the HPCR data are dependent on the assumptions made with regard to the parasitic load of the common rail fuel pump.

Table 1 - Performance variables and measurement devices for the single cylinder engine facility.

Parameter	Instrument	Measurement technique
Fuel Consumption	AVL 734 Fuel Balance	Gravimetric
Brake Torque	Electric Dynamometer	Load Cell
In-cylinder Pressure	AVL QH33D	Cooled piezoelectric pressure measurement, scaled by means of polytropic compression method
NO _x Emissions	California Analytical Instruments, 400 HCLD with NO ₂ →NO converter and Peltier chiller	Chemiluminescent measurement cell
HC Emissions	California Analytical Instruments, 300 M FID	Heated Flame Ionization Detector (FID)
CO and CO ₂ Emissions	California Analytical Instruments, Model 300	Infrared (IR) gas analyzer after chiller
Particulate Matter Emissions	AVL SPC 472	Partial flow dilution tunnel with constant dilution ratio

Summary of SCE to MCE Correlation Study:

The SCE was completed and commissioned in 2004. At that point in time, the SCE operating conditions (e.g. setting of external subsystems and load) to represent “equivalent” multi-cylinder engine notch conditions were set according to historic multi-cylinder engine data (e.g. manifold air pressure, temperature, fuel flow, air flow). This current study compared a sample of recent data from the multi-cylinder engine and single cylinder engine. The data compared consists of a sweep of injection timing with the unit pump fuel system at notch 8.

The results of the summary show that the single cylinder engine accurately predicts the performance trends of a multi-cylinder engine despite the differences in air handling system and friction between the two engine systems. In addition to exploring the performance trends with timing swing, the in-cylinder pressure profiles from both engines systems were compared to explore the heat release rate and the air handing. Although there are differences in air handling, the combustion event is very similar between the two systems. We are in the process a drafting an ASME publication on the single cylinder engine set-up procedure the performance correlation to the MCE.

Planned activity for next quarter

Over the next quarter, the single cylinder engine’s exhaust system is being upgraded for vibration durability and to handle higher exhaust gas temperatures. After the hardware is installed, the baseline procedure will be repeated for all notch conditions.



Task 3: Hybrid Energy Storage

Subtask 3.3: Lab test advanced energy storage prototype modules and system

Post-test teardown of the shock and vibration tested hybrid-bus-design battery revealed extensive insulation wear and breakage of some internal connections. Modifications to the battery arrangement will be required to meet the locomotive shock and vibration requirements. The vendor developed modified design concepts, for internal battery arrangement and outer packaging, to address vibration robustness issues, and started detailed design and analysis.

When the hybrid energy storage battery system is integrated with the locomotive, it may be subject to transient voltages and short circuits which occasionally are experienced in the locomotive electrical traction system. Further, some batteries may be in a dormant cold state (say at ambient temperature) where the internal resistance is extremely high. In response to the vendor's experience that battery current flow in a cold state may result in battery damage, a cell-level test program was performed to develop limits to use for the vehicle system design.

Testing of room temperature battery cells with a range of applied terminal voltages showed that voltage reversal at the terminals of each cell must be avoided. A second set of long-term tests was started at constant current levels to more accurately define the limits. An unattended 2-week-duration test was prematurely terminated by a power interruption during the holiday period, and that test was resumed in January 2006. Testing at 130 deg C has shown much lower internal cell resistance and consequently higher levels of current response to applied voltages.

Task 4: Fuel Optimization Control Strategies

The following activities brought Task 4 to closure. Studies were completed to quantify robustness of optimal driving plans to parameter uncertainties, and to compare benefits obtained with a sophisticated optimization calculation with some greatly simplified sub-optimal calculations. The results will assist tradeoff between fuel usage and accuracy of parameter values. The Trip Optimizer human-machine-interface has been tested by a broad range of experienced and inexperienced personnel in order to identify difficulties in understanding the task planning and execution activities.

Task 5: Demonstrate hybrid locomotive concept with full-scale storage modules, and fuel optimizer

The vendor notified GE that advanced locomotive-design batteries will be delivered May to December 2006. Consequently the Task 5 demonstration of the advanced battery hybrid locomotive will be delayed into 2007.