APPENDIX E PROJECT - MODEL-BASED (SMART) ENGINE FOR PRACTICAL EMISSIONS REDUCTION

Status Report
First Quarter 2003

PROGRAM GOALS

The objective of this program is to achieve reduced NOx emissions levels, through the development and demonstration of an advanced model-based controlled heavy-duty diesel engine, at or below 1.50 g/hp-hr.

APPROACH

This R&D program focuses on an advanced, integrated, model-based approach to control the engine functions and operation. This is targeted at emissions reduction of the future heavy-duty diesel engine (HDDE). Current state-of-the-art production engine controls have limitations due to the use of multiple table-based approach to control engine critical functions. A model-based approach, inclusive of integrating and optimizing certain subsystems, is expected to lead to minimized overall emissions without substantial deterioration in engine function and performance. The model-based approach offers the premise to address some of the current system shortcomings, thereby achieving better tradeoffs between engine emissions, performance, and fuel economy.

TASK-BY-TASK PROGRESS REPORT

Task 1 – MBC Approaches Screening And Down-Selection

DDC reviewed and compiled the most promising candidate control theory techniques for heavy-duty diesel engine application. The investigation not only identified applicable control strategies, but also provided the strategic path for controls technology development. Current state of the art Proportional Integral Derivative (PID) control techniques are being used as benchmarks to compare the identified control methods during successive program tasks.

Task 2 – Engine Modeling

A real-time mean value engine model as well as a more detailed cycle simulation engine model was created to characterize the subject truck engine. Lumped parameter representation is utilized, including submodels for the key elements and subsystems of the engine, including those anticipated for future emission regulations. Base engine components are modeled with a mix of empirical tables and physics-based algorithms. In addition to the real-time engine models, which are designed to operate in real-time synchronization with actual engine events, a cycle simulation engine model was formulated to handle the more detailed spatial and temporal investigations. It also provides a means to validate the less detailed real-time engine model.

Tasks 3 - Controls Modeling

The control requirements and issues were grouped according to each major engine system. A comparison of experimental engine test data and the output from the real-time model (aka virtual engine) was conducted, for the purposes of validating the tools for further development application. Submodel enhancements were introduced to remove operating instabilities and expand the range of investigation that the engine models could be applied. The correlation between experimental engine test data and the virtual engine were substantially improved.

Task 4 - Rapid Controls Prototyping

A rapid prototyping controls system was chosen and configured to the purposes of the project, including required adaptations to the engine and test facility. Hardware and software adjustments made to ensure properly synchronized I/O (input/output) communication between the engine's electronic control module, engine and test facility sensing systems, the data acquisition system, and the control console. The resulting system provides necessary functions for controlling, monitoring, and automating real-time experiments for more effective controller development. Thus, the rapid prototyping system enables control strategy development and evaluation without being constrained to the hardware or software limitations of the production controller.

Phase I Results

Preliminary investigations were launched using the newly established combination of virtual and experimental labs so to demonstrate the viability of this rapid prototyping capability and development process, while also initiating quantitative progress on the engine emission output.

Phase I work included implementation of the new controller into the rapid prototyping environment. After a significant period of hardware and software debugging, the controller was working properly in the engine test cell.

Off-line validation of the virtual engine was conducted for both steady state and transient processes. The virtual engine shows good correlation to experimental test data. The capability of the virtual engine to accurately predict measured engine response combined with the ability to model different actuator and sensor delays makes the tool very useful for 'what if' analysis.

Model based predictive schemes were developed and coded in real-time models to replace some elements of the conventional controller.

Without controller tuning, initial test results proved that the novel control concept represented the basic physics quite well, while providing stable engine operation.

Several virtual sensors concepts were successfully prototyped, engine tested and then upgraded (or simplified) to run faster than their original version. Refinement of several virtual sensors for highly transient or dynamic engine operation is in progress. Based on engine experimental data, corrective relationships are being identified to further improve accuracy.

Task 5 - Phase II Planning

The Phase II plan was detailed. It is now being executed, feeding from the results of the Phase I completion.

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Task 6 - Nonlinear Controls

The advanced technology controller includes increased capability and fidelity to monitor and control subsystem thermodynamics in non-linear and stochastic operating environments, all of which will be crucial to achieve compliance with future emission standards in all modes of engine operation.

Supported by other technology sponsorships at DDC, preparations are underway to introduce advanced technology hardware to the advanced controller engine testbed.

Task 7 – Virtual Sensors

The first class of virtual sensors that emphasize engine protection has been developed beyond the concept feasibility stage, signaling true prototype status. Completed verification efforts entailed several rounds of steady state and transient engine test investigations to confirm the ability to capture relevant operational effects. However, there are still many technical challenges left before final product validation and implementation can be completed.

For the second class of virtual sensors associated with this program, representative on-board simulation of in-cylinder engine conditions are being pursued while minimizing reliance on new physical sensor technology. The primary objective(s) of this class of sensors is to simultaneously improve the consistency of engine system performance while ensuring tighter emission compliance and mitigating severe engine material cost increases otherwise associated with more stringent emission standards.

Task 8 – On-Board Diagnostics

Several unique methods to achieve on-board detection of malfunctioning or overstressed engine system was verified during engine testing. These findings will be incorporated into a master prognostic and diagnostic package.

Task 9 – Iterative Upgrades & Testing

With test cell resource constraints requiring that engine testing of new software or hardware be compressed into limited timeframes, an efficient and systematic means for logging, analyzing, and communicating engine test results is paramount. During this reporting period, an internal website and logging methodology was created to help facilitate cross-functional team review of data and forward planning of engine tests.

In addition, a model-based approach was developed to determine optimal set points designed to meet a target emission level. The approach is driven by emission calculated errors derived from the difference between the target and the feedback.

Under parallel programs at DDC, an experimental engine was previously built with prototype hardware capabilities. Now, the associated on-board models are being adapted to adequately represent the additional flexibility of the hardware.

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Summary of Program Status

Major challenges remain to achieve the overall program goal of 1.5 g/hp-hr NOx. Relative to the original program plan, actual calendar time to pass through a single development cycle from creation of control concept to successful implementation of a fully functioning transient engine control system was underestimated. On March 19, 2003 an extension of the completion date of the project to January 27, 2005 was requested.

Although no major technical roadblocks have been encountered per se to-date, a systematic, yet aggressive technology development effort will require a few development cycle iterations. During CY2003, the core technology engine controller will approach full transient operational status for the first time.