VIII. ABSTRACTS OF NEWLY AWARDED PROJECTS

VIII.1 Application of Wide Spectrum Voltammetric Sensors to Exhaust NOx Measurement

Streamline Automation, LLC

Streamline Automation, LLC will perform a two-year effort to develop a NOx sensor based upon gas voltammetric technology. Liquid-phase voltammetry has been used for over fifty years for qualitative and quantitative analysis through forced oxidation or reduction at an electrode surface. In 1995, Argonne National Laboratory developed a process for gas phase voltammetry, which received an R&D 100 award for the research. The technology was licensed to Streamline Automation and is the basis for development of the NOx sensor.

The overall objective is to demonstrate that a practical automotive NOx sensor can be successfully developed based upon *voltammetric* gas sensor technology. Voltammetry is an electrochemical analysis technique that has been relied upon for many decades for *identification* and *quantification* of chemicals in *liquid* solutions and compounds. In voltammetry, an electrical current is produced by applying a high-speed, time varying potential to the cell. This forces chemical components to react (dissociate) at potentials characteristic to each species. The induced current vs. applied potential data is called a "voltammogram", or electrochemical spectrum, which is then digitally processed to extract and identify the reacting chemical species and their concentrations.

Current NOx sensors suffer from interference by exhaust gases and inability to measure ammonia, which is needed for most current NOx control strategies. The gas voltammetric method has minimal contamination and interference effects from exhaust components, can qualitatively and quantitatively measure the individual NOx species (NO_2 and NO_3), ammonia, and is capable of measuring organic exhaust species.

Several generations of gas sensors based upon voltammetry have now been produced and used as an electronic nose to detect and quantify *gaseous* chemicals in complex mixtures. While the materials that these electrochemical cells are fabricated from are similar enough to existing automotive oxygen sensors to expect similar life spans and durability - the voltammetry method of operation is significantly more capable providing far more information with which to describe the gas composition. In voltammetry *all* gases in the mixture are routinely considered "target" analytes and any issues of interferences become as simple as discarding responses outside of a defined (NOx) reaction potential. This broad-spectrum response also promotes the evolution of a voltammetric multiple gas sensor to monitor several tailpipe emissions simultaneously. The project will develop the voltammetric sensor for vehicle applications, with a form factor suitable for incorporation into standard vehicle hardware systems. This will be followed by proof-of-principle characterization and testing on operating spark-ignition and compression-ignition engines. The range of operation is expected to be from 0 to 200 ppm NOx with an accuracy of 5 ppm. The solid state device lifetime is anticipated to be 100,000 for maintenance, with a 500,000 mile lifetime.

VIII.2 Start-of-Combustion Sensor for HCCI Engines

TIAX, LLC

Homogeneous charge compression ignition (HCCI) has elevated the need for start-of-combustion (SOC) sensors. HCCI engines have been the focus of engine research recently, primarily because HCCI offers higher thermal efficiency than the conventional spark-ignition (SI) engines and significantly lower NOx and soot emissions than conventional compression ignition (CI) engines, and offer the potential for fuel neutrality.

The objective of the Phase I research is to answer two fundamental questions: can the accelerometer-based SOC sensor provide adequate SOC event capture to control an HCCI engine in a feedback loop, and will the sensor system meet cost, durability, and software efficiency (speed) targets? For successful completion of Phase I, the accelerometer-based combustion sensor must provide enough discernable signal resolution at low-load conditions (where the lowest signal-to-noise ratio exists) such that the SOC may be readily identified to the required accuracy. During Phase I, reliable algorithms for identification of SOC from the reconstructed pressure trace must be developed to meet accuracy and speed specifications. The processing code efficiency (response time of control system) must be rapid enough (meeting the specifications determined in the initial task) that control decisions may be made and implemented. The interface with the HCCI actuation/control mechanism (variable valve timing/fuel injection, etc) must be rapid and robust enough to allow the control mechanisms an opportunity to change engine conditions. The sensor(s) must be durable enough to meet all conditions of the engine operating regime and still provide accurate data for the life of the engine. The sensor and algorithm must also demonstrate “technology robustness” in application across engines of the same type (same model, different serial number) as a measure of production and commercial feasibility. The detailed specifications for each of these six criteria will be determined in the initial task of the project.

The objective of Phase II is to develop a pre-production prototype which implements the algorithms into a functional control system ready for vehicle testing. Phase II is contingent upon Phase I meeting the success criteria detailed above, in which case we assume that Continental will be heavily involved in Phase II. The team will design and optimize the SOC sensor as a system to meet commercialization targets. Phase II will address left over issues not resolved in Phase I. From Phase I, the two best algorithms will be selected, as well as the two best accelerometer sensor designs and engine mounting packages. These packages and algorithms will be down-selected and optimized. Continental will be heavily involved through this process, and from this selection process pre-production prototypes will be made.

If successful, the benefits will be significant. The emergence of a durable and effective SOC sensor will solve what is a critical challenge to the viability of HCCI engine platforms. The SOC sensor could be an enabler for a new breed of engines saving 15-20% of petroleum used in transportation, while meeting or exceeding 2010 emission targets.

VIII.3 On-Board Engine Exhaust Particulate Matter Sensor for HCCI and Conventional Diesel Engines

Matthew J. Hall and Ronald D. Matthews
The University of Texas at Austin

Eric Andrews and Phanindra Garimella
Cummins Engine Company

To meet the 2007/2010 particulate matter regulations, new diagnostic techniques will be useful to control the engine-out particulate emissions, control regeneration of the diesel particulate filter (DPF), and/or signal failure of the DPF. The primary goal of this research is to refine and complete development of an on-board particulate matter (PM) sensor, bringing it to a point where it can be commercialized and marketed. The work will be performed through a joint effort between the University of Texas at Austin and the Cummins Engine Company. The ability of this novel PM sensor concept to detect and quantify the carbonaceous fraction of particulate matter emissions in engine exhaust, with millisecond response time, has been well established.

The focus of Phase 1 will be the development of a system that will account for the velocity dependence of the sensor and will quantify the sensitivity and dynamic range of the sensor. Two concepts will be examined. First, a pitot tube will be used in the exhaust to measure the exhaust velocity. This velocity will be used in a known correlation to determine the PM concentration. The second concept is to have a separate flow circuit for the PM sensor. Instead of inserting the sensor directly into the exhaust system, a by-pass flow circuit would be attached at this point, with a small downstream blower used to create a fixed volumetric flow rate of exhaust gases past the sensor that is independent of engine operating conditions.

Phase 2 of the project will focus on applications of the PM sensor to diesel homogeneous charge compression ignition (HCCI) and on refining the design and performance of the sensor system through engine testing. The PM sensor system performance will be characterized with an EPA 2007 level-emissions diesel engine. The PM sensor will be examined for use during the mode switch from HCCI operation to conventional diesel operation at high loads and for individual cylinder control that produce PM emissions problems. Individual cylinder control of injection parameters, for example, may be an enabling technology for HCCI engines. The PM sensor system will also be evaluated as an indicator of DPF failure and as a tool to indicate when the trap needs regeneration.

VIII.4 The Development of a Robust Accelerometer-Based Start of Combustion Sensing System

Westport Power, Inc.

Westport Power, Inc. will perform a two-year project developing an accelerometer-based start-of-combustion (SOC) sensing system using standard, inexpensive automotive knock sensors (accelerometers) and advanced signal processing. An inexpensive and reliable SOC sensing system is the critical enabling technology for the introduction of high-efficiency homogeneous charge compression ignition (HCCI) engines. Other standard combustion technologies (compression and spark ignited engines) would also stand to benefit from the availability of a robust, low-cost combustion sensing system. Westport's accelerometer-based SOC sensing system will enable engine makers to improve engine efficiency (by HCCI or other means) by providing a real-time feedback signal that characterizes the combustion on every engine cycle. Westport has already demonstrated control of HCCI using the accelerometer-based SOC sensing system on two engines. As such, this technology is already beyond the proof-of-concept stage, but critical lack-of-robustness problems are preventing the commercial application of the SOC sensing technology. The work outlined in this project will resolve the key lack-of-robustness issues. Specifically, it needs a method to compensate for engine-to-engine variations, and a method to compensate for sensor-to-sensor variations. Potential solutions to these two sources of variation have been identified.

The objective of the proposed work is to resolve the main lack-of-robustness problems: the engine-to-engine and sensor-to-sensor variation issues. The work is divided into three distinct phases. In the first phase of work, methods will be developed to compensate for engine-to-engine variation. The goal of the second phase of work is to develop sensor-to-sensor compensation techniques. The goal of the third phase of work is to demonstrate the accelerometer-based SOC measurement system in a test cell.

The work outlined in this project will resolve the key lack-of-robustness issues. Upon completion of this work, SOC sensor technology will be ready for commercialization. Integration of the SOC sensor technology with any engine application which can benefit from its use will be possible. Westport's intention is that, at the end of this work, the accelerometer-based SOC sensing system could be used in a commercial HCCI-based engine. If the SOC sensing technology developed during this project enables the introduction of HCCI engines, substantial fuel economy and environmental benefits will be realized.