October 22, 1998

Dr. David Crouch
Energy-Related Inventions Program
U.S. Department of Energy
Washington, DC 20585


Dear Dr. Crouch,

This letter is to report upon progress made on this project during the second period of the no-cost time extension effective April 1 through December 31, 1998.

In parallel with this progress report, we are submitting our Federal Cash Transaction Report for this period with supporting detailed spreadsheets, and the Request for Advance or Reimbursement for the month of October. These items are being submitted directly to DOE Accounts Payable Division, CR-54, with copies to you under separate cover.

Accomplishments and Lessons Learned, July 1 – September 30, 1998

In July 1998, Loragen moved into a new facility in an industrial park at 3576 Empleo St., Unit 1, San Luis Obispo. Two new technical staff were hired: Brian Hemme, MS Electrical Engineering, was employed in December 1997, and assumed a full-time salaried position as senior engineer in July, 1998. Kyle Wayman, a computer engineering student at Cal Poly, was hired full-time for summer 1998, and part-time during the academic year. Plans to incorporate Loragen have been delayed until January 1999, due to the accelerated schedule of work on this project.

As described in the previous report, we have shifted our focus to a retrofit product suitable for installation on existing mechanically-governed diesel engines. Included in this potential market are almost all diesel-powered passenger cars and light trucks manufactured prior to the introduction of the most recent "clean diesel" engines equipped with particulate traps and electronic controls. Also included are heavy-duty trucks, transit vehicles, school buses, and agricultural equipment. This system is intended to prevent existing diesel engines from overfueling to the point of visible particulate emissions (smoke), while allowing maximum smoke-limited torque under all operating conditions. A hardware diagram for the retrofit system, tentatively designated the Adaptive Diesel Smoke Control (ADSC), is shown in Figure 1 below.

In its simplest form, the system employs a microcontroller and a specialized exhaust particulate emission sensor to continuously generate and update an adaptive throttle-limit map. This map specifies a maximum allowable throttle position as a function of engine speed and coolant temperature. For mechanically regulated fuel injection systems, the throttle position limit is mechanized via a linear position actuator attached to the fuel injection pump. For electronically regulated injection systems, this limit is mechanized by interception and modification of the electronic throttle input to the system.
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Indirect fuel delivery measurement inferred from injector needle lift provides a feedback signal for more precise fuel limit-regulation, which is advantageous since in retrofit situations, the actual fuel sleeve or rack position cannot usually be accessed. The only external fuel control mechanism available is the throttle. In its simplest and lowest cost embodiment, however, this system should be functional but somewhat less accurate, even without this fuel quantity sensing mechanism. We are developing versions of the system both with and without this feature, each appropriate to different engines and vehicular applications.

The concept of using direct measurement of exhaust smoke for real-time feedback control of fuel quantity is not new, having been patented in 1986 at American Bosch division of United Technologies (the former employer of the project director). An actual system utilizing this concept has never been developed or commercialized due to two technical obstacles to be described later (and possibly several institutional ones) which are all overcome by the ADSC. The American Bosch patent, which previously blocked commercialization of systems based upon or similar to this concept, was abandoned and expired in July 1998.

The first of the previous technical obstacles referred to above is related to the fundamental approach of attempting real-time feedback control of the fuel quantity by direct smoke sensing. In the real-time approach, there is a considerable lag between the detection of the exhaust composition and the actuation of any possible fuel limiting mechanism. This results in control loop instability and periods of smoke during throttle or load transients, even with the feedback control fully operational. The ADSC system does not implement real-time control in the same sense. It is a "learning" system that adaptively updates a smoke-limit map based upon exhaust sensor feedback. The system learns and continuously adapts the smoke limit fuel quantity over time, such that the control actually operates "open-loop" using the adaptive map. The enabling technology behind this learning control method, real-time digital signal processing, was not considered practical only a few years ago.

The second of the previous technical obstacles referred to above is the difficulty of implementing a reliable particulate sensor that can be permanently located in the engine exhaust stream. This is the most essential element of any such control system. Although our engineering of a final product is not complete, we feel that we have developed a reliable sensor for this application. The sensor is not novel in its basic sensing phenomena, which are well understood and used in other applications, but rather in the way that we can use these phenomena reliably in the exhaust stream of a diesel engine. A simplified cross-sectional diagram of the sensor can be seen in Figure 1, which shows the electrostatic version of the sensor. The main problems of sensing particulates in the exhaust stream are the coking of the sensor elements (either optical or electrostatic) and the excessive heat in this environment. Referring to the figure, the ADSC sensor is unique in that it imbeds the sensor elements at each end a sensor section in "pockets" into which a small pressurized air stream is injected. This small air flow prevents intrusion of exhaust particulates onto the sensor elements and effectively cools the sensor elements, preventing damage. The air supply is provided by either a conventional engine-mounted air pump or a small electrically driven compressor. The sensor section is located in the exhaust plumbing between the exhaust manifold and muffler.

One other distinguishing feature of the ADSC which uniquely qualifies it for retrofit applications is that it functions as an overriding "limited authority" type of control. It operates as a dynamic throttle position limiter rather than as a direct fuel control. This overcomes the problem that in retrofit situations, it is not possible to directly access or limit the fuel delivery means (fuel sleeve or rack) which is internal to the fuel injection pump. Since ADSC sets the throttle limit as an instantaneous function of the engine speed (and temperature), it actually parallels the internal function of the mechanical governor, mechanizing the appropriate fuel quantity limit via the only externally-accessible injection control input, the throttle.

As discussed in the previous report, we are attempting to anticipate the transition to high-pressure direct injection systems in newer diesel vehicles, to retain the applicability of both needle-lift based fuel quantity sensing and direct exhaust particulate sensing to these newer technologies. The present approach is consistent with these developments, as well as developments in diesel particulate trap technologies. As previously pointed out, precise fuel control is an absolute necessity for the survival of
any type of diesel particulate trap; a single heavy particulate burst and clog or poison a trap or filter to a
degree that prevents on-board regeneration or purging.

Our immediate technical objectives are to complete the development and testing of this system on a
dynamometer-mounted Isuzu 1.8L diesel test engine, and deploy this system in at least two field
applications. The first is a passenger auto or light truck application using either our existing 1982 Isuzu
l-Mark diesel sedan or a similar displacement light truck. Due to the age of our test vehicle, we feel that
demonstration in a newer vehicle, possibly a small diesel truck might prove a better marketing tool,
especially since diesel light trucks have been far more common than diesel passenger cars during the
past ten years. Note that the '82 l-mark was originally purchased for this project demonstration since our
electronically-controlled test engine, donated by Isuzu's research facility in Japan, was a drop-in fit for
this vehicle. Our completed demonstration and test vehicle will be subjected to comparative EPA-
standard emissions testing (with and without ADEC).

Progress with our engine-based system development testing has been slowed by a change in the
availability of the dynamometer-testing facility at Cal Poly that we used for prior work. Our proposed
workplan specified the use of this facility for these tests. After waiting since May for approval from Cal
Poly, we asked your permission in September to rebudget grant funds to permit us to purchase a
dynamometer apparatus to perform these tests. The total cost of this equipment was less than $5,000.
At the time of this report, the equipment is being shipped from the manufacturer in Colorado to our
facility, and should be operational by mid-November. This late alternative places considerable pressure
on us to complete the final calibration and programming tasks required for the prototype demonstration
system. We have anticipated this intense effort in November and prepared accordingly by eliminating
any conflicting demands on our time. The final grant period, October 1 through December 31, 1998, is
expected to be a period of intense effort to complete the project tasks and transition into a market
demonstration phase.

With respect to the commercialization of this product, we have made arrangements with Santa Maria
Area Transit, a local county transit operator, for the deployment of the ADSC system on one of their in-
service buses over an adequate period of time to assess its effectiveness, reliability and acceptance by
the transit district. We are pursuing similar arrangements with a local school district, for possible
demonstration on one or more of their diesel school buses (which presently exhibit a severe problem with
smoke emissions under full load). We are in the process of exploring local grant opportunities which
would fund the large-scale deployment and testing of this system in one or more of these bus fleets.
State of California and local San Luis Obispo and Santa Barbara County funding opportunities have been
identified, accessible through the local Air Pollution Control District (APCD), Air Quality Management
District (AQMD), and the State-administered Petroleum Violation Escrow Account (PVEA) fund. We
intend to actively pursue these options in order to gain additional valuable test data, and, if successful, to
create broad awareness of the system and its potential benefits for existing diesel vehicle fleets.

Thank you for your understanding and continued support of this project. If you have any questions,
please don't hesitate to call me at (805) 781-8461 (Loragen office) or (805) 343-2556 (home office).
Also, I would like to extend an open invitation to you to visit the Loragen facility and observe our
progress. Please let me know if such an opportunity is possible.

Sincerely,

C. Arthur MacCarley, Ph.D., PE.
Project Director

Attachments: Figure 1 referenced in technical discussion.

Cc: S. C. Jones, Office of Headquarters of Procurement, HR-542
Figure 1. Retrofit Version, Adaptive Diesel Smoke Control (ADSC).