Technology Review

Advanced ECO-FIRE™ Single Coil Capacitive Discharge Distributor Ignition System

Combustion Electromagnetic Incorporated
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PREFACE

The STEP technology assessment process is designed to identify those technologies that will support the economic and environmental/energy goals of the Commonwealth of Massachusetts and may benefit from STEP assistance. The process is meant to be one of screening, in which independent technical specialists evaluate technologies. Recommendation from this process does not constitute an endorsement of the technology or of the absolute validity of the technology. Rather, STEP technical assessments attest only that, through the screening process, the reviewers feel there may be benefit to the Commonwealth of Massachusetts.

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TECHNOLOGY PROPONENT

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CEI has developed a new, high energy, ignition system capable of igniting very lean mixtures in internal combustion engines. CEI holds all rights to the product: **ECO-FIRE™** capacitive discharge (CD) distributor ignition system and 42 V based inductive coil-per-plug system. The company has performed several prototype demonstrations but has not completed a manufacturing prototype, which is expected to be finished within six months from the date financing is secured.

CEI is requesting assistance from the STEP program so that it can publicize its technology to state and federal agencies; get help in obtaining federal/state/private sources of funding; get independent validation of test results; and obtain a review of their business plan and strategy.

TECHNOLOGY DESCRIPTION

The technology proposed by CEI would increase the fuel efficiency and reduce emission of automobile engines. CEI owns three patented technologies: high energy ignition systems[1]; ignition flow coupling; and engine combustion chamber designs for use with flow coupled high energy ignition to provide the best possible fuel economy and low emission through lean burn and high exhaust gas re-circulation (EGR) combustion. The key technology is the ignition system, and the other two technologies derive their main benefit from the high-energy ignition technology.

The core technology identified by CEI is their ignition system, which is protected under several patents, more notably US patent 5,947,093 dated September 1999, for its capacitive discharge ignition[2], and US patent 6,142,130, dated November, 2000, for its 42 volt based coil-per-plug inductive ignition. All other applications have been patented or the patent is pending. CEI owns some twenty patents and patent applications. They cover two types of ignition system, inductive and capacitive discharge (CD), and methods and design for their use. The present invention relates to ignition systems for internal combustion (IC) engines, and particularly to high power high-energy ignition with magnetic stress-balanced coils. High-energy ignition is essential to the operation of IC engines using difficult-to-ignite mixtures, such as very lean mixtures, high exhaust residual or high EGR mixtures, and the more difficult-to-ignite alcohol fuel mixtures. Such mixtures require high power and high energy. The high power high energy CD ignition with stress-balanced coil disclosed and the 42 V based inductive ignition can deliver the required power and energy with a minimization in the size and cost of parts to make the system practical.

The CEI technology can be used as a replacement to current car ignition systems with the added advantage of allowing higher levels of EGR to reduce NOx emissions. The other option would be in the design of new engines by reshaping the combustion chamber to achieve high fuel economy through ignition-flow coupling. Early tests revealed fuel economy increase of up to 20% and NOx emission reduction of up to 90% compared to standard ignitions operating at stoichiometry.

TECHNICAL FEASIBILITY

Spark ignition engines utilize ignition systems that can develop up to about 30 kV for breakdown of the spark plug gap and typically deliver current levels in the range of 30 to 100 mA. Measurements and analysis of these systems show that the energy transfer efficiency is very low, typically of the order of ten percent or less[3,7]. After the spark is formed, most of the energy is delivered to resistances in the transformer, spark plug wires and spark plugs. For all older and most modern engines this operating level is adequate, but not necessarily optimum. However it will not meet the needs of lean burn and some alternate fuel engines that require higher energy discharges to successfully ignite the air/fuel mixtures. To meet the requirements for increased ignition power and energy, ignition systems have to be designed to operate at higher transfer efficiencies.

Catalytic converters were developed for automobiles to meet clean-air standards established in the 1970s and 1980s. Based on federal clean air standards to be phased in over the next several years, automakers must reduce nitrogen oxide emissions. Lean burn engines are a promising technique to further reduce both nitrogen oxide and hydrocarbon/carbon monoxide emissions. Higher lean burn levels improve nitrogen oxide formation. The nitrogen oxide reduction is due to cooler flame temperatures. This is not feasible under lean conditions using current technology catalysts that will work efficiently only at a rich air/fuel ratio.

Engine efficiency and emissions depend on several factors including how quickly the fuel burns and on the temperature of the flame. To make an engine that is both efficient and has low emissions, the major objective is to burn as much of the fuel as fully as possible, as quickly as possible at a temperature that is as low as practicable. As a general rule, a lean burn gives grater efficiency and lower NOx emission. This advantage is negated by the fact that the leaner the mixture the slower the flame propagation and more susceptible it is to dying or quenching. CEI was able to design a high power high-energy ignition system with stress-balanced coil that can deliver the required power and energy to make the system practical.

It is well known that power-enhanced ignitions extend the lean burn limits and transient response of spark ignition engines[4,5]. Experiments with such ignitions date to at least the early 1970's. More recently, experiments with certain low inductance peaking capacitors across the spark plugs have also demonstrated similar improvements plus lower hydrocarbon emissions and fuel consumption, particularly with older engines. Additional benefits include better starting and cold running performance and lower combustion pressure variability. The **ECO-FIRE™** single coil CD distributor ignition system and 42V based coil-per-plug inductive ignition designed by CEI belongs in this group of high-energy ignition systems[6].

Key to the patented technologies is a low-cost ignition system that, as the submission claims, delivers three to five times more spark energy, higher ignition efficiency, more spark power, and greater flow resistance. Components enabling the high-powered spark are:

- A power converter that steps up battery voltage to 42V from the standard 12V.
- Higher switching currents from standard 600V insulated gate bipolar transistors (IGBT).
- A proprietary false-firing arrestor.
- A low-loss snubber that reduces switching losses and sends coil leakage energy back to the battery.

The submission has data from tests performed at GM, Mazda, Lucas Industries and Chrysler that show better fuel economy and lower emission with very lean fuel mixtures when compared to standard ignitions. The latest tests of an early version of CEI's ignition took place in 1995 at Chrysler Corp. A prototype of capacitive discharge ignition system on a 4-cylinder engine was operated under relatively cold conditions to simulate the early part of the car's drive cycle-when engine stability, emissions, and fuel economy are at their lowest. The test results showed better engine stability and a 3% to 20% improvement in fuel economy.

The submission has limited experimental data on fuel economy and emissions. However, it is also understood that the proposed technology is still in the development stage with plans to finish it within six months of obtaining adequate financing.

TEST

To demonstrate the ignition system capabilities, a test was performed on a single cylinder, two-valve engine with the latest design of **ECO-FIRE™** single coil CD distributor ignition system. The test was performed at CEI facility and the purpose of it was to witness results and point to uncertainties if they were detected.

The test was performed on a Wisconsin S-14D industrial engine that was converted by replacing the cylinder and head with parts designed and machined by CEI. The engine performance was recorded at about 2450 rpm with 7 ft-lb torque set at a DY-9D Go-Power water brake dynamometer. Fuel consumption was measured gravimetrically and calibrated after the test by a weighing technique. The torque readings accuracy was also measured and calibrated after the test. Power was calculated from the torque and speed measurements. The ignition timing was set manually by shaft with direct point readings. The accuracy of engine rpm and timing was calibrated before the test by strobe light. The ignition timing was adjusted manually and was in the range of 15 to 55 degrees. Emissions of O_2, CO_2, CO, NO and HC were measured with Nova gas analyzer that was calibrated before the test. Air/Fuel Ratio (AFR) was determined from O_2 and CO_2 readings and by flow across a calibrated orifice.

Results for Brake Specific Fuel Consumption (BSFC) versus AFR are presented in Figure 1. The range for AFR was from ~14 to 30. The BSFC data matches well with the results presented by M. Ward[7]. Data for a Ford of Europe 4 cylinder engine and Ricardo HRCC engine were taken from literature provided by CEI and are presented for comparison only. Since friction losses are normally higher for one-cylinder engines then four-cylinder engines, the BSFC values should be corrected to compensate for this difference. This correction will reduce the measured BSFC value. Since the test data for 4 cylinder engines was not available, an estimate for the range of BSFC values was made[8,9], and presented in Figure 1.

Engine emissions were measured over the AFR range described above. Data for HC and NO emissions were presented in Figure 2. Readings for NO for AFR below 20 were above gas analyzer sensitivity range that was 2000 ppm. The system also provided high stability of engine operation and was able to overcome intentionally generated misfiring for all test points with AFR above 25. A skip fire detector was used to verify the lack of misfire.

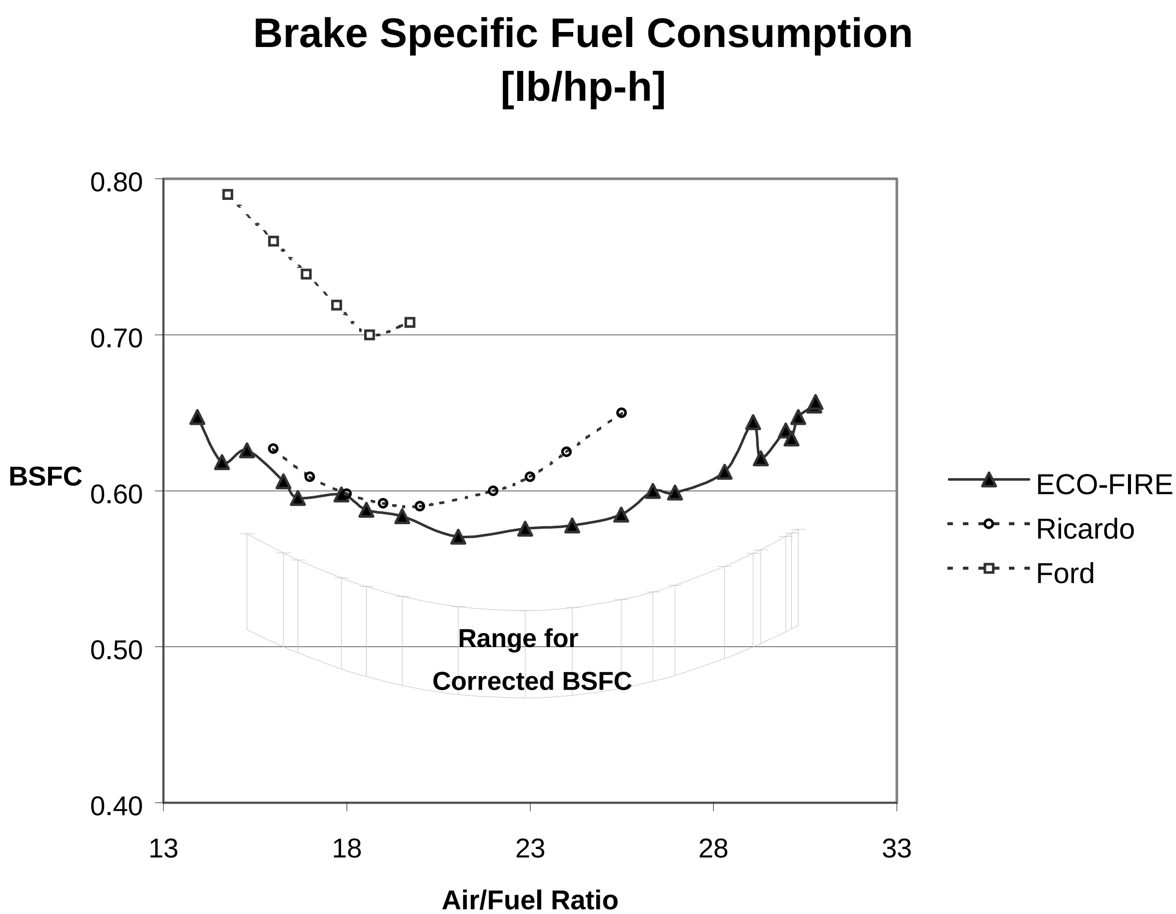

Figure 1. Specific Fuel Consumption

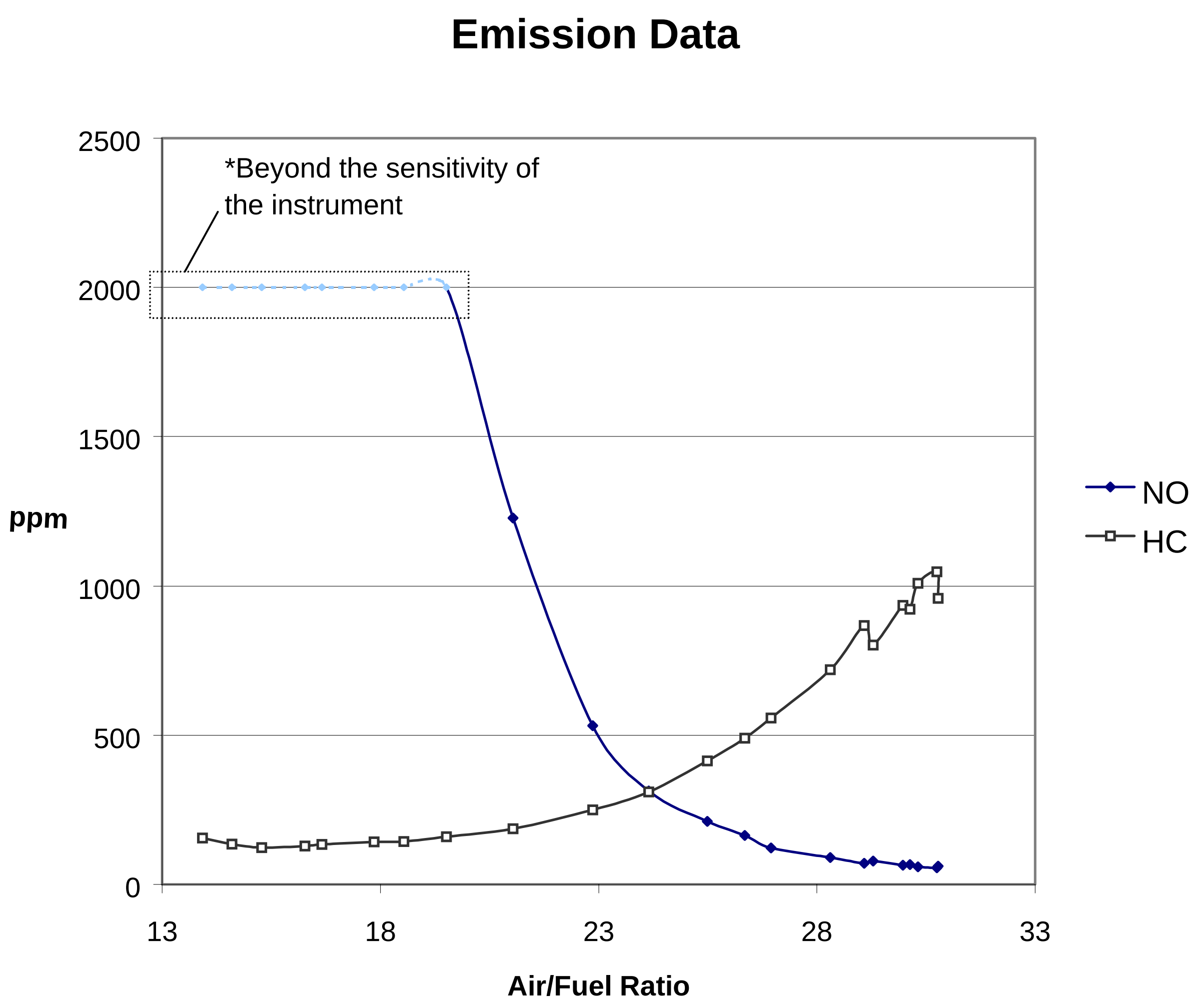

Figure 2. Emission Data

Competing Technologies

Car manufacturers are already designing lean combustion engines designed to enhance fuel efficiency without sacrificing power or drive-ability. Mitsubishi is currently producing both 3-valve and 4-valve versions of a lean combustion engine, the Mitsubishi Vertical Vortex (MVV). They are in use in subcompact and compact cars in Japan. While most conventional petrol engines require an air-fuel ratio of 14.7:1, the MVV[10] can achieve complete combustion with an air-fuel ratio as high as 25:1. More air in the mix means reduced fuel use. At 40 km/h, the MVV engine provides 13 % better fuel economy than conventional engines. They have also developed a GDI[11] (Gasoline Direct Injection) engine with Ultra-Lean combustion with an AFR of 40:1.

SUMMARY

The ECO-FIRE™ engine ignition system used to perform this test is a prototype developed over several years by CEI. The company has performed several prototype demonstrations and is expected to be finishing a manufacturing prototype within six months from the date financing is secured. In this process, additional development and optimization may help improve results obtained during the test. Extensive testing should be conducted to obtain more operating data and dynamic effects. An extensive, long term test will help to make the determination if the design is suitable for automotive applications. Substantial development effort would be required to incorporate ECO-FIRE™ ignition system into an engine control strategy to utilize lean burn technology. Based on the data presented so far it would be reasonable to expect, that ECO-FIRE™ could achieve results similar to data obtained during the test in a fully integrated system. ECO-FIRE™ ignition has shown improved fuel economy and lower emissions.

REFERENCES

1. Hybrid Ignition with Stress Balanced Coils, US Patent 5,947,093, September 7, 1999.
2. Low Inductance High Energy Inductive Ignition System, US Patent 6,142,130, November 7, 2000
3. G.J. Rohwein, S.R. Babcock, M.T. Buttram and L.S. Camilli. "Advanced Automotive Ignition System ", Sandia National Laboratories, 2000.
4. R.W. Anderson and J.R. Asik, "Lean Air-Fuel Ignition System Comparison In Fast Burn Engine", SAE Paper 850076
5. R. Maly, "Spark Ignition: Its Physics and Effects on the Internal Combustion Process", published in: Fuel Economy in Road Vehicles Powered By Spark Ignition Engines, Hilliard, J.C. and Springer, G.S. (Ed.), Plenum, New York, 1984.
6. M.A.V. Ward, "A New Spark Ignition System for Lean Mixtures Based on a New Approach to Spark Ignition", SAE 890475, 1989.
7. M.A.V. Ward, "High-Energy Spark-Flow Coupling in an IC Engine for Ultra-Lean and High EGR Mixtures", SAE 2001-01-0548, 2001.
8. K.S. Herbsleb, L. Lorenzen and E. Kofoed. "Lean Combustion in a High Compression Four Stroke Gasoline Engine", SAE 810786
9. C.F. Taylor and E.S. Taylor. "The Internal-Combustion Engine", International Textbook Co.1996.
10. Mitsubishi AutoMagic, "Lean and Clean Engine Technology", http://www.mitsubishi-motors.co.jp/inter/technology/env_04.html
11. Mitsubishi AutoMagic, "GDI™ Gasoline Direct Injection", http://web1.mitsubishi-motors.co.jp/inter/technology/GDIEC/index.html