PLASMA IGNITER, LLC

The Next Gen Ignition System

To achieve current and future CAFE standards, as well as fuel economy and emission requirements in Europe and the rest of the globe, manufacturers are implementing several strategies: reducing vehicle size and weight, increasing power plant complexity by adding turbo and superchargers, modifying the combustion and emission cleanup environment, and introducing a broader range of hybrid and all electric vehicles.

Additionally, to take advantage of the enormous increase in natural gas production in the United States and elsewhere, natural gas and multi-fuel vehicles are increasing in market share, which will require significant design and development considerations in the near future. All of these strategies are necessary but ignore the greatest potential for improvements: the ability to efficiently ignite and consume ultra-lean mixtures of both liquid and gaseous fuels, providing complete combustion while minimizing harmful emissions.

Plasma Igniter has developed the Coaxial Cavity Resonator Ignition System (CCRIS), a compact, dual signal next generation ignition system. Testing has demonstrated that the CCRIS is superior in igniting conventional lean fuel/air mixtures and particularly effective in igniting alternative fuels. The CCRIS is effective as a low-energy ignition source at high compression ratios, creates lower levels of controlled emissions and, most importantly, provides on-board diagnostic capabilities for real-time ignition and combustion modifications.

The Broader Impact

The United States has set new CAFE standards for passenger vehicles of 35.5 miles per gallon (mpg) required by 2016 and 54.5 mpg required by 2025. This is a 65% increase over nine years—a mandate that has not been achieved in the history of internal combustion engine development. Similarly, emissions and fuel economy requirements are being implemented internationally that will require engine manufacturers worldwide to rethink and redesign the way they build and control engines. Improving the overall efficiency of these engines will require a better way to ignite and combust the fuel while monitoring and modifying the combustion process in real time: the complete combustion process achievable through the CCRIS.

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PLASMA IGNITER LLC™

The Current Situation

Major problems with current spark-ignited systems include:

Poor fuel economy: The 54.5 mpg CAFE requirement has caused the auto industry to re-evaluate their current ignition systems. Experts believe that these new and future requirements can only be met by advanced ignition systems, and not by any Direct Current (DC) spark ignited system.

Emissions: Complex, multi-stage catalysts are the norm for reducing greenhouse gases, hydrocarbons, and oxides of nitrogen (NO_X) from emissions of typical internal combustion engines. Most of these emissions are the result of ultra-hot ignition and incomplete combustion within the engine.

Lean burn: One way to increase fuel economy and decrease emissions simultaneously is to ignite mixtures with less fuel under partial engine load conditions. Current spark-ignited systems struggle with this, especially near idling speeds.

Energy intensive: High compression ratios normally require excessive energy levels for ignition, which increases NO_X production and decreases total engine efficiency.

Locating fuel/air molecules: Because fuel is only ignited near the arc gap in a standard spark plug, a suitable fuel/air mixture needs to be present to ignite. As mixtures get leaner and leaner, this becomes a growing problem. The CCRIS provides a more global ignition initiation.

The Plasma Igniter System

Coaxial Cavity Resonator Ignition System

CCRIS uses dual signal microwave coronal plasma to achieve predictable low-temperature ignition of lean and ultra-lean fuel mixtures with fewer unburned hydrocarbons, lower NO_X, and less undesirable emissions than conventional spark ignition systems.

QWCCR Ignition Plug

Quarter Wave Coaxial Cavity Resonator

The heart of the system, the Quarter Wave Coaxial Cavity Resonator (QWCCR), is a novel use of a microwave plasma source as a spark plug replacement. The QWCCR is a dual signal radio frequency (RF) and DC impedance transformer designed around a quarter of the operating wavelength step-up phenomena. As RF power is introduced into the QWCCR, voltage is transformed from a low voltage input to a high voltage at the discharge tip; providing a more efficient and safer transfer of energy into the cylinder. Additionally, high voltage DC is used to supplement the coronal plasma formation at high compression ratios. The resulting high-voltage electromagnetic wave generates a freestanding, localized, sustainable, and finely controlled microwave plasma that can serve as an internal combustion engine ignition source.

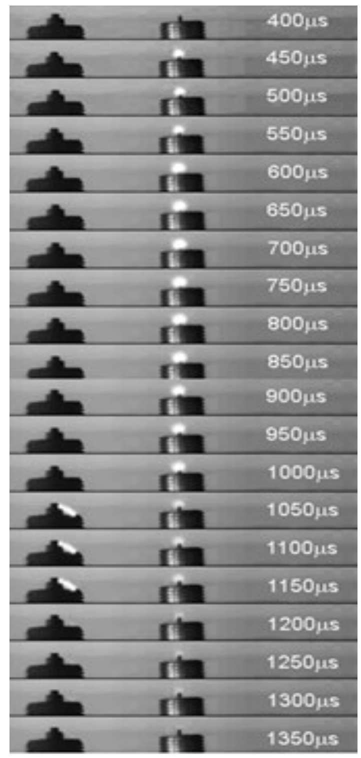
Distinguishable Achievements

While the underlying technology is over two decades old, coronal plasma ignition as applied to the internal combustion engine industry is still in its infancy.

Plasma Igniter has licensed the initial plasma igniter concept, developed the CCRIS, and in the last several years has refined and demonstrated the technology.

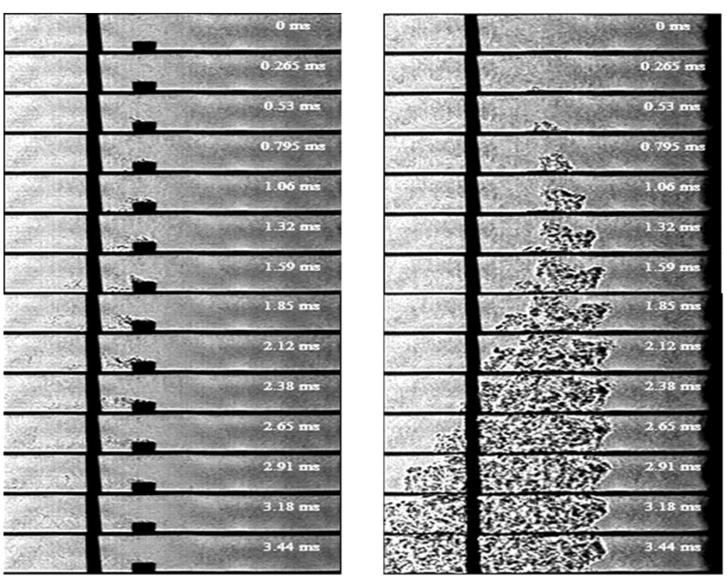
Most notably:

- Research that led to a set of design parameters for the igniter and demonstrated combustion initiated by several different prototype ignitors.
- The time scale and amplitude of the coronal plasma formation has been defined and made controllable.
- Investigation of several different dielectric materials that would allow for a plasma discharge yet provide a barrier to the internal combustion environment.
- Experiments to determine the cold start capability of Jet A fuel ignited using the QWCCR in comparison to a conventional electrode based spark plug.
- Demonstrated the efficacy of the Plasma Igniter for use with multiple fuel environments.
- Independent tests conducted at a National Laboratory that demonstrated superior lean combustion results for gaseous fuels with the QWCCR.



Ignition Duration
Spark (left) vs. CCRIS (right)

Current Testing



Flame-front Propagation (20% Lean conditions)
Spark (left) vs. CCRIS (right)

Current testing is being performed at the Center for Alternate Fuels, Engines, and Emissions (CAFEE) at West Virginia University, soon to be validated in global laboratories.

Patent Protection

The CCRIS is embodied in U.S. Patent Nos. 5,361,737; 7,721,697; 8,783,220; and 8,887,683. Additional domestic and international patents are pending.

Integrated In-Cylinder Diagnostics

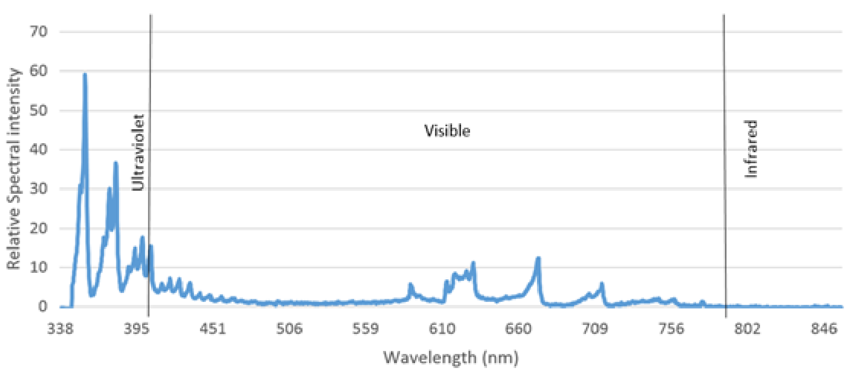
The QWCCR can be used as both an ignition device, because of its ability to step up voltage and form coronal plasma, and a sensing device, because of its inherent resonance structure. The resonator is designed to switch from a sensing device to an ignition device in microseconds.

Due to its electromagnetic properties, the QWCCR is able to detect changes in pressure and temperature, composition of the fuel/air mixture, and the presence of an ignition. All of these events trigger a change in the QWCCR that can be easily predicted, such as the change of in-cylinder temperature and pressure. This real-time and on-board diagnostics capability provides the ability to constantly upgrade the form, type, and amount of energy that can be delivered to provide clean and complete combustion, and to do so in the same engine cycle.

Extended Effects

QWCCR is more than an ignition source, it's a dual signal electromagnetic emitter. The effects of the device can be felt not only at the igniter's tip, they also permeate the cylinder. Because of this, the CCRIS has the ability to ignite and move fuel molecules in the combustion environment, allowing for fuels to become more readily ignitable.

Research has shown that the CCRIS system increases the indicated mean effective pressure, reduces the burn duration, and improves the tradeoff between thermal efficiency and brake specific NO_X emissions.



Spectrometry of CCRIS — UV, Visible, and IR

Additionally, spectral photometry verifies that energy released by the CCRIS exists primarily in the ultraviolet spectrum—where most of the ignition potential exists.

Developmental Partners Sought

Plasma Igniter, LLC, the world-wide license holder for this technology, is seeking industrial and OEM partners to advance this technology into the global marketplace.