Investigation of the fundamentals of low-energy nanosecond pulse ignition

Final CRADA Report

Energy Systems Division

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prepared by

Thomas Wallner¹, Riccardo Scarcelli¹, Anqi Zhang¹, James Sevik¹, Munidhar Biruduganti¹,
Bipin Bihari¹, Katarzyna E. Matusik¹, Daniel J. Duke¹, Christopher F. Powell¹, Alan L.
Kastengren²

Energy Systems Division¹, X-ray Science Division², Argonne National Laboratory

Participants: Transient Plasma Systems, Inc.

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Participant Dollars: \$40,000

Argonne PI: Thomas Wallner

Participant(s):

Transient Plasma Systems, Inc. \$40,000
Name Participant Dollars

1751 Torrance Blvd, Suite K, Torrance, CA 90501
Complete Address

Name \$ _____
Participant Dollars

Complete Address

Name \$ _____
Participant Dollars

Complete Address

DOE Program _____
Manager:

Summary of Major Accomplishments:

A detailed investigation of the fundamentals of low-energy nanosecond pulse ignition was performed with the objective to overcome the barrier presented by limited knowledge and characterization of non-equilibrium plasma ignition for realistic internal combustion engine applications (be it in the automotive or power generation field) and shed light on the mechanisms which improve the performance of the advanced TPS ignition system compared to conventional state-of-the-art hardware. Three main tasks of the research included experimental evaluation on a single-cylinder automotive gasoline engine, experimental evaluation on a single-cylinder stationary natural gas engine and energy quantification using x-ray diagnostics.

Summary of Major Accomplishments:

GDI engine data showed that the TPS system can significantly improve dilution tolerance and combustion stability with respect to production spark systems. The EGR tolerance could be improved by as much as 15% (from 25 to 28.5% EGR). GDI engine results also showed that there is the potential to improve dilution tolerance and thermal efficiency even further in the future primarily by using plugs with larger gap sizes (which requires higher peak voltage) and secondly by employing a larger number of pulses. Both high voltage and large number of pulses could increase the chance of an arcing event during the low-temperature plasma discharge in GDI engines, which is not the desired operating mode of the NPD system because it reduces the spark-plug lifetime. GDI engine optical observations highlighted how the mixture pre-conditioning from pulse to pulse plays a key role in determining the transition from low-temperature plasma (LTP) mode to spark (SSB) mode during the train of pulses.

The natural gas engine operated successfully only when the TPS system produced an arc. The detection of transition between LTP and SSB modes was almost non-existent on this engine platform. The hypothesis of the observational differences could be due to lower compression ratio, different fuels (high octane rating of natural gas), and different turbulence signatures at time of ignition among others. The TPS system allowed engine operation at very lean conditions (λ : 1.72). Even though the COV was higher than the industry standard (5%), the engine operated consistently unlike other ignition systems thanks to the multi-pulse sequential ignition.

X-ray radiography results indicate that the propensity for arcing to occur decreased with increasing ambient pressure. At low ambient pressure, the probability of arcing increased with pulse number, presumably due to local ionization of gas in the gap by previous pulsing events. Due to the relatively low amount of heat deposited into the system for non-arcing conditions, the volume displacement of air relied on averaging a large number of events in order to measure a statistically significant signal. The volume displacement was approximately two orders of magnitude greater for arcing vs. non-arcing events. At low ambient pressure, the non-arcing conditions featured a gradual increase in the volume displacement with increasing pulse number, which peaked at the last triggered pulse before gradually decreasing. In the case of an arcing event at low ambient pressure, the deposited thermal energy was found to be approximately three times as much as that of a conventional ignition coil at similar conditions; this trend reversed in a high ambient pressure environment.

In future endeavors, it would be best to avoid all arcing events in order to keep the geometry as consistent as possible throughout the experiments. Future investigation should focus on how to optimize the plug geometry or control the pulse delivery to prevent arcing events from occurring.

Summary of Technology Transfer Benefits to Industry:

Identifying the fundamentals of low-energy nanosecond pulse ignition aids the CRADA partner in developing and marketing improved ignition systems specifically targeting automotive as well as stationary applications.

Other Information/Results: (Papers, Inventions, Software, etc.)

A detailed report of the investigation of the fundamentals of low-energy nanosecond pulse ignition was developed, reviewed and provided to the CRADA partner.

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Argonne National Laboratory
9700 South Cass Avenue, Bldg. 362
Argonne, IL 60439

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