

Advanced Ignition Systems Evaluations for High-Dilution SI Engines

Thomas Briggs, Terrence Alger, and Barrett Mangold
Southwest Research Institute

ABSTRACT

A series of ignition systems were evaluated for their suitability for high-EGR SI engine applications. Testing was performed in a constant-volume combustion chamber and in a single-cylinder research engine, with EGR rates of up to 40% evaluated. All of the evaluated systems were able to initiate combustion at a simulated 20% EGR level, but not all of the resulting combustion rates were adequate for stable engine operation. High energy spark discharge systems were better, and could ignite a flame at up to 40% simulated EGR, though again the combustion rates were slow relative to that required for stable engine performance. The most effective systems for stable combustion at high EGR rates were systems which created a large effective flame kernel and/or a long kernel lifetime, such as a torch-style prechamber spark plug or a corona discharge igniter. These results suggest that achieving good engine performance with high EGR rates will require changes to the ignition system of an SI engine to produce a more robust flame kernel.

CITATION: Briggs, T., Alger, T., and Mangold, B., "Advanced Ignition Systems Evaluations for High-Dilution SI Engines," *SAE Int. J. Engines* 7(4):2014, doi:10.4271/2014-01-2625.

INTRODUCTION

High dilution gasoline engines pose unique demands on ignition systems. The addition of EGR changes the gas composition that must support a spark, it generally slows the flame propagation process, and it increases the cylinder pressure due to higher trapped mass. All of these make a conventional spark ignition system less ideally suited for use in a dilute SI engine [1].

To combat this challenge, a number of new ignition system concepts have been created in order to provide more stable operation in engines under high dilution conditions. The simplest change is to replace a conventional spark plug with a fine-wire spark plug. Multiple ground electrodes are also commonly seen, and surface discharge spark plugs. All of these designs can work with a conventional ignition circuit. Alternately, the spark plug can be replaced with a plug having an enclosed tip; the unburned gases are forced into the plug tip during the compression stroke and are ignited, exiting as a jet flame.

By re-imagining the ignition circuit, even more energetic ignition systems can be developed. These include the ECCOS system [2], which forms a cold plasma using a high-frequency electrostatic field to cause the breakdown. The effective area of the spark is then very large and can overcome the flame speed reduction inherent in dilute combustion. Laser ignition is also commonly researched [3], with the potential of very high energy density at the laser focal point. This high energy density can provide excellent ignition characteristics.

In the present study, these various ignition systems were compared through testing in both a constant-volume optical combustion vessel and in a single-cylinder research engine. High-speed Schlieren imaging was used to characterize the flame growth early in the combustion process. The engine tests were used to quantify the EGR tolerance of each ignition system configuration, with the goal of identifying the best system for use in a high-EGR SI engine.

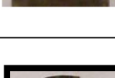
TEST MATRIX

The various ignition systems were separated into three groups based on their broad characteristics. The first group was the "production style" systems. These had conventional hardware layouts but incorporated improved igniter hardware or ignition circuitry. The second group consisted of the "high energy" systems that used a combination of inductive coils and capacitors to increase the amount of energy delivered and/or the method or rate at which it was delivered. The final group was the "unique" category, which included hardware that did not easily correspond to a conventional ignition system. A listing of the tested systems is given in [Table 1](#).

The ignition systems were initially evaluated in a quiescent pressurized combustion vessel under varying levels of simulated EGR dilution. The dilution was simulated by addition of CO₂ at the appropriate level to simulate the dilution of 20-40% EGR. This permitted a rapid comparison of the different systems' ability to reliably ignite a fuel-air mixture and provided detail on the initial flame growth rate. In this case, the focus of the work was on the very initial flame kernel. While

cylinder pressure was measured during the test, the portion of the experiment during which the flame kernel was growing in the region of the spark plug consumed so little fuel that the impact on the chamber pressure was essentially negligible. The test conditions are given in Table 2. The ignition systems were tested at increasing EGR levels until the system failed to ignite the stoichiometric fuel/air mixture in the vessel.

Table 1. Listing of ignition systems tested, with delivered energy and photograph of the igniter

Igniter	Delivered Energy	Photo
Conventional 3 mm nickel-plated copper electrode	30 mJ	
Iridium #1 0.6 mm iridium tipped electrode	30 mJ	
Iridium #2 0.5 mm iridium tipped electrode	30 mJ	
Multi-torch	30 mJ	
Surface #1	30 mJ	
Surface #2	30 mJ	
Iridium #2 with high energy coil	100 mJ	
Iridium #3 0.6 mm iridium center electrode with 0.8 mm platinum ground electrode	100 mJ	
Iridium #4 0.6 mm iridium center electrode with 0.6 mm platinum ground electrode	100 mJ	
Surface #2 with CD ignition system	55 mJ (capacitive)	
Iridium #4 with very high energy coil	300 mJ (inductive)	
Plasma jet plug	2.4 J	
Rail plug	2.4 J	

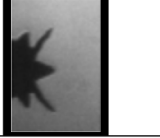
Platinum spark plug with extended duration circuit 0.8 mm platinum electrode	1.2 J	
Dual spark open chamber plug	2.4 J	
Dual spark torch plug	2.4 J	
Cold plasma plug	4 J	
Laser ignition	80 mJ	

Table 2. Combustion vessel test conditions

Initial pressure	6.8 bar
Initial gas	393 K
Gas mixture	NIST-certified mixture of O ₂ , N ₂ , and CO ₂ to approximate 20%, 30% or 40% EGR
Fuel type	Iso-octane
Igniter dwell time	5 ms

For the combustion vessel experiments, high-speed Schlieren imaging was performed to track the development of the flame kernel during the ignition process. The overall layout of the combustion vessel and optical path is shown in Figure 1.

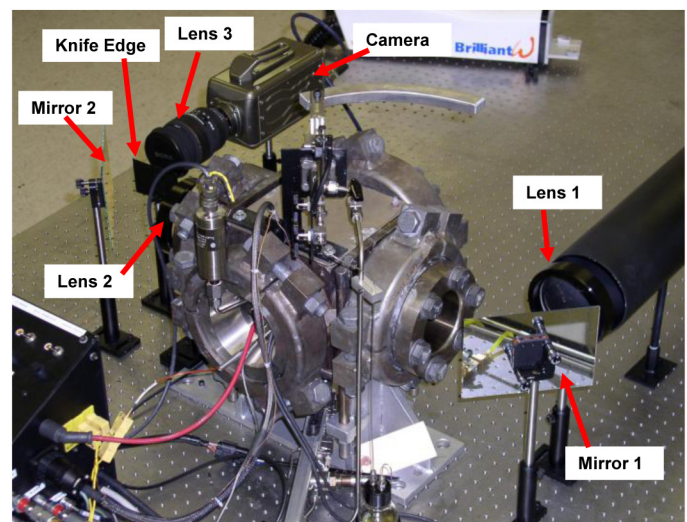


Figure 1. Layout of the optical path and combustion vessel