Ignition Systems for Heavy-Duty Natural-Gas Engines

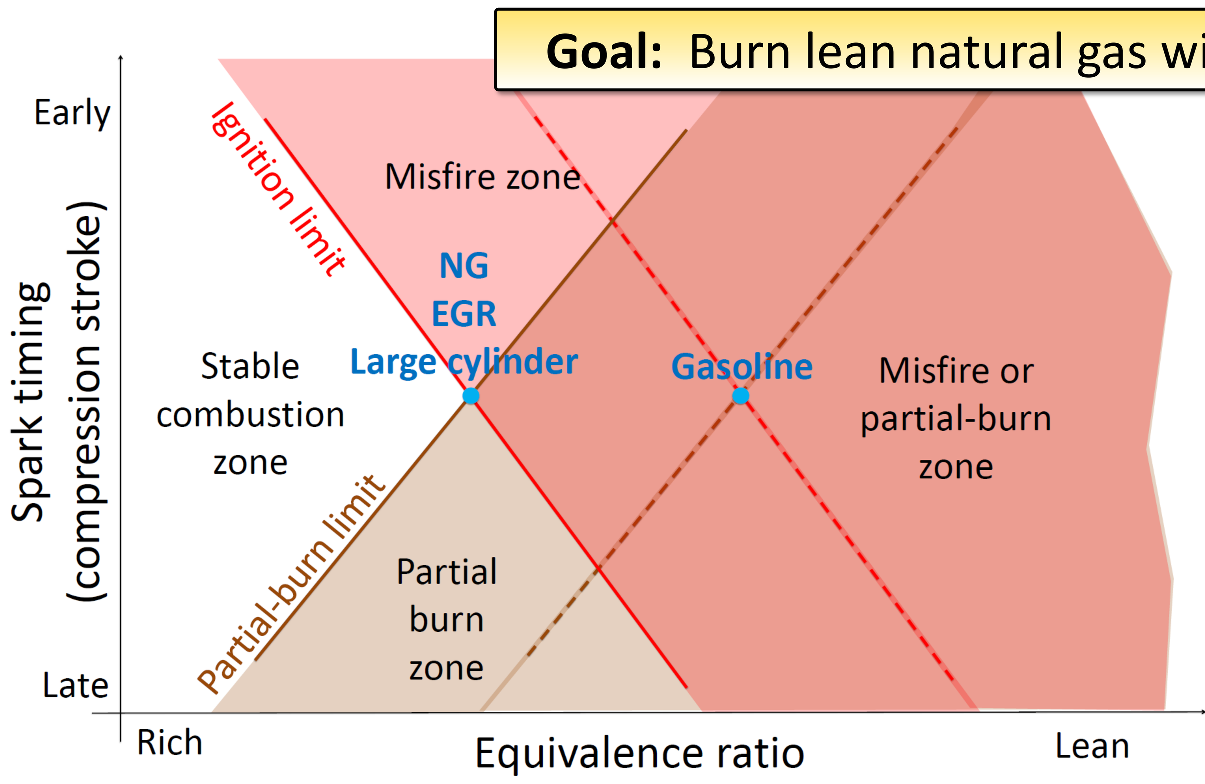
Ahmet Mazacioglu, Michael C. Gross, and Volker Sick
Department of Mechanical Engineering, University of Michigan

Abstract

This program will experimentally select and implement the advanced ignition systems best suited for burning lean natural gas (NG) that is also diluted by exhaust-gas recirculation (EGR) in heavy-duty (HD) engines. Thorough literature review identified corona ignition and turbulent-jet ignition (TJI) as the technologies with the most potential for this application. A high-speed, dual-axis, infrared borescope/camera setup was designed to study the ignition and flame-kernel growth produced by these ignition systems in a modified production HD engine. Performance of each system will be characterized and optimized under multiple operating conditions in order to guide implementation in truck fleets.

1. Problem

Goal: Burn lean natural gas with up to ~20% EGR in a heavy-duty engine.



Adapted from [1]

Advantages of lean natural-gas combustion with EGR
- The price of NG is stable, usually well below diesel or gasoline.
- NG emissions contain less soot and other particulates.
- Lean burning improves fuel efficiency.
- EGR reduces NO_x formation.

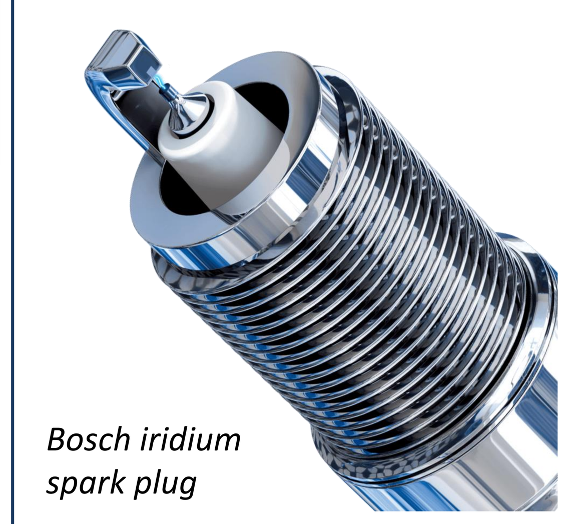
Challenges of natural-gas ignition in HD engines
- NG has a high autoignition temperature.
- EGR is not ignitable; it dilutes the combustible mixture.
- NG has low flame speeds; EGR further reduces flame speeds.
- HD engines have larger cylinders, increase the flame-travel distances for complete combustion.

2. Ignition Systems

Which ignition systems can prevent misfires and partial-burns?

Systems investigated
- Inductive-discharge
- Capacitive-discharge
- Dual-coil
- Controlled-electronic
- Breakdown
- Laser
- Multi-plug
- Rail-plug
- Microwave-assisted
- Corona
- ns-pulsed plasma
- Turbulent jet
- Supersonic jet
- Diesel pilot

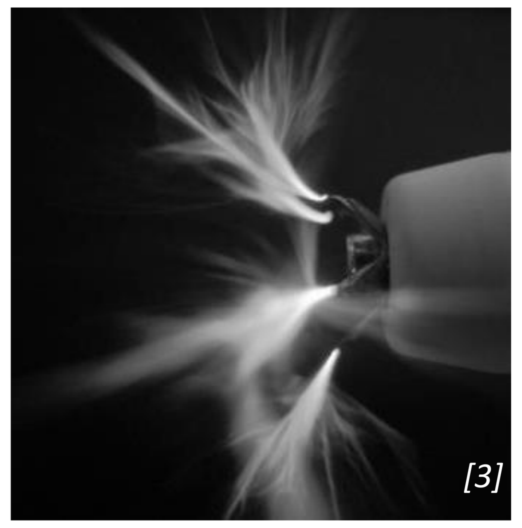
Conventional


Bosch iridium spark plug

[2]

- Low energy (~30-100 mJ)
- Point ignition (~1 mm spark)

Corona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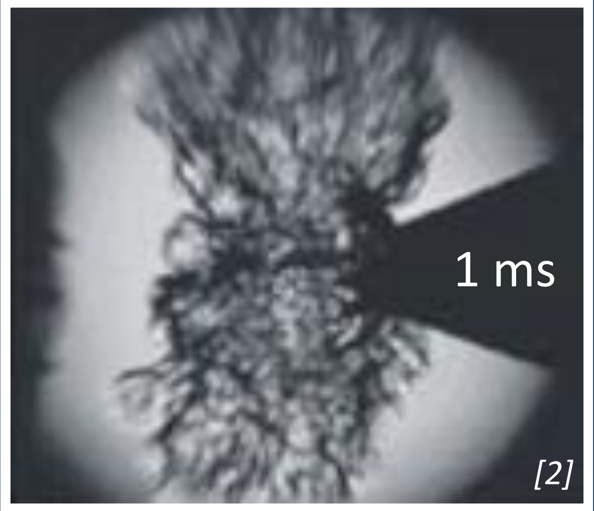
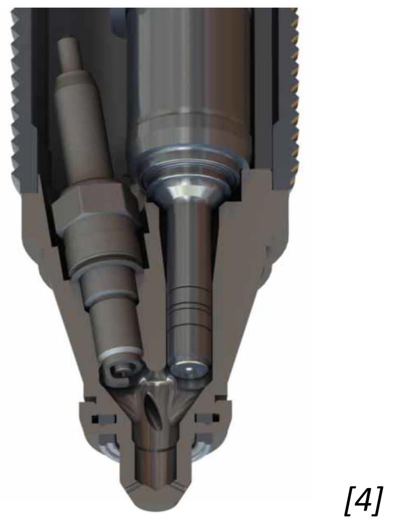


[2]

- High energy (~4000 mJ)
- Volume ignition (multiple ~25 mm streamers)

Turbulent Jet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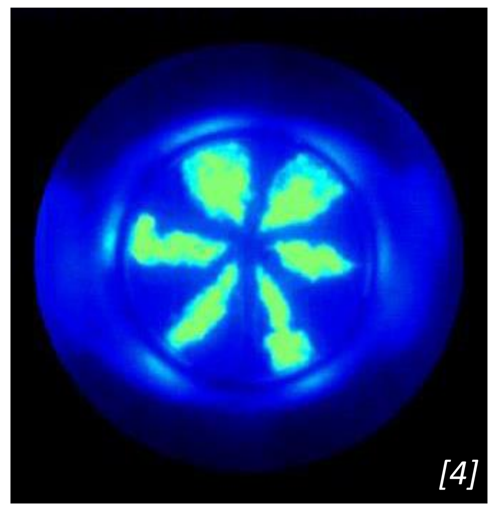
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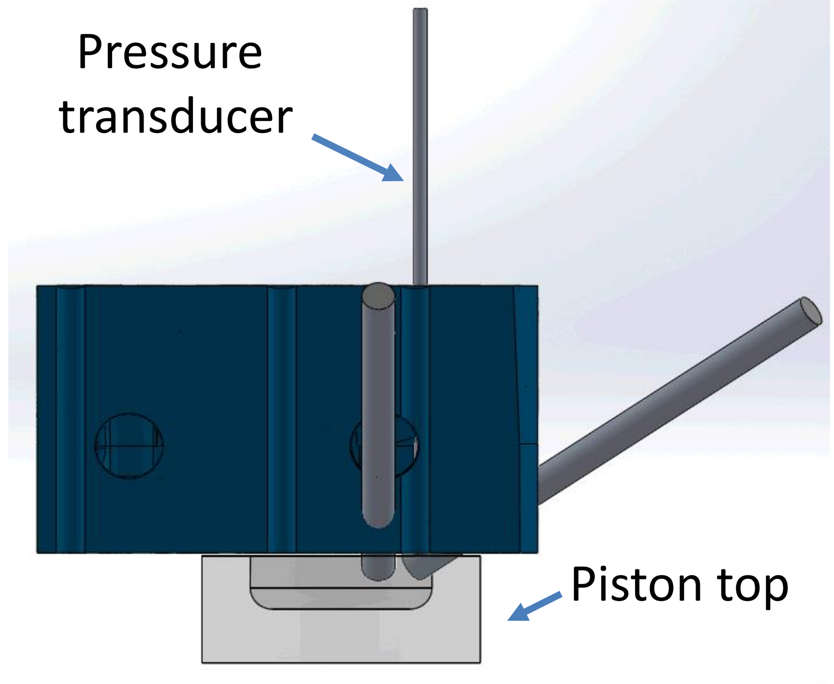
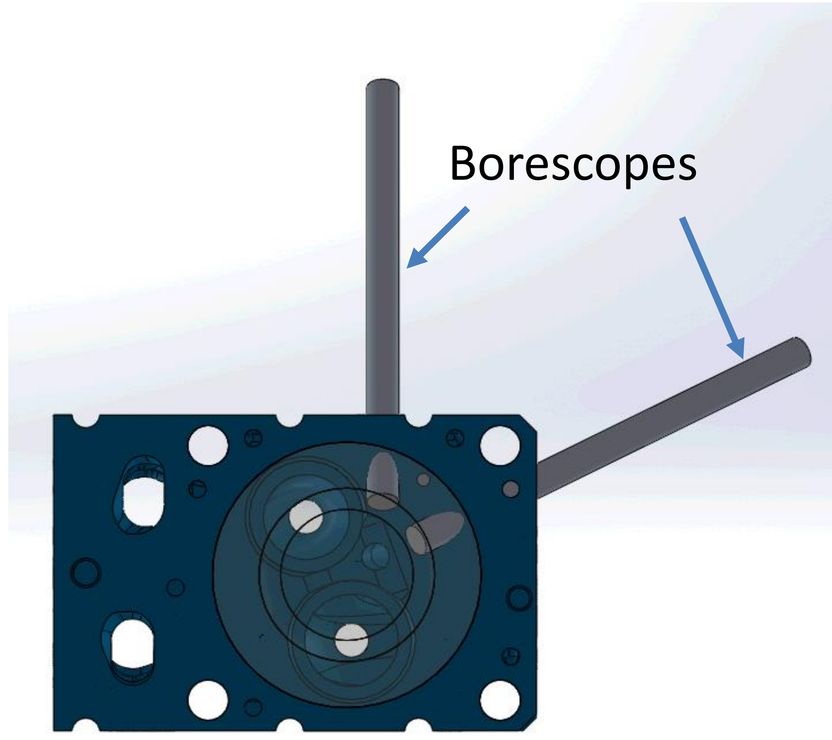
- Hot burned gas jets
- Distributed ignition

3. Measurements

Modified Engine Head





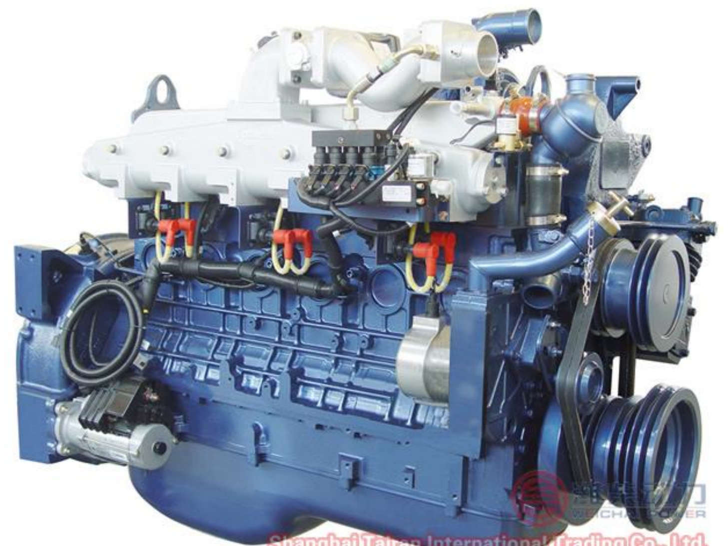
Ignition energy
- Ignition voltage and current are measured as functions of time during the electrical discharge.

Flame kernel growth
- A production engine's head is modified for optical access.
- 2-axis borescopic view provides 3D information about the ignition event and the flame kernel growth.
- High-speed (865 Hz or higher) infrared cameras provide fine temporal resolution and sensitivity to H_2O emission.
- H_2O emission is a good proxy for the flame zone and burned-gas region.
- Custom adapter enables LaVision ICOS spectroscopic sensor to replace one borescope when needed.

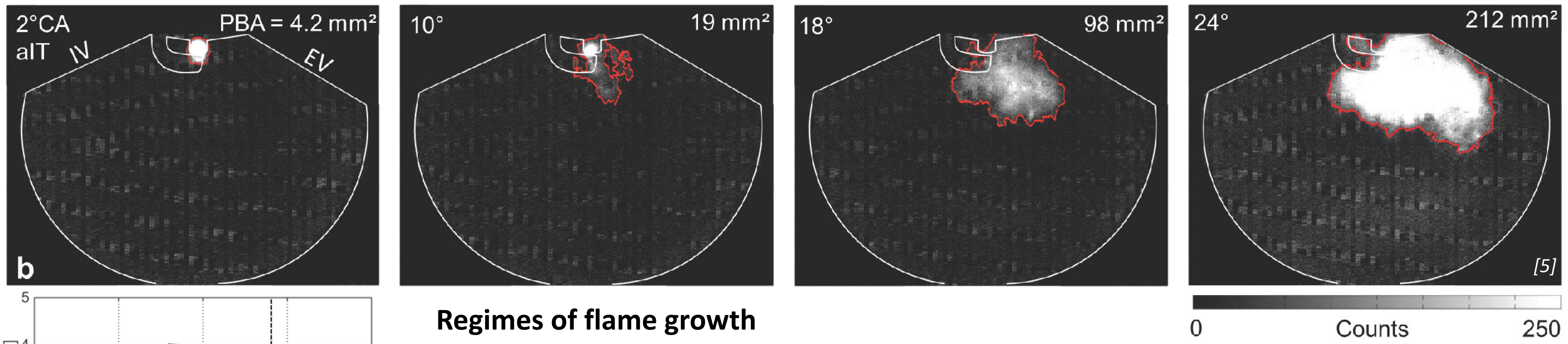
Performance
- In-cylinder pressures are measured by a pressure transducer.

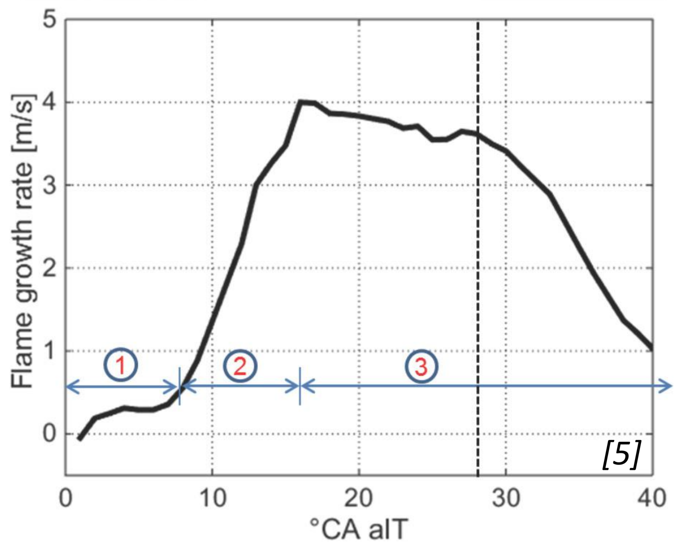
Emissions
- Species concentrations in the exhaust gas are measured.

Fuel economy
- Intake fuel concentration is monitored.


Weichai WP10NG

4. Planned Analysis





Regimes of flame growth
1. Ignition: Near-zero propagation speed.
2. Development of the flame kernel: Accelerated flame due to increased wrinkling.
3. Turbulent flame propagation: Nearly constant speed if in-cylinder turbulence levels are ~uniform. Propagation speed decreases when flames reach the wall.

Questions to be answered
- How are these regimes influenced by the ignition method?
- What are the correlations between flame growth, performance, and emissions?

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