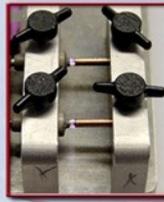


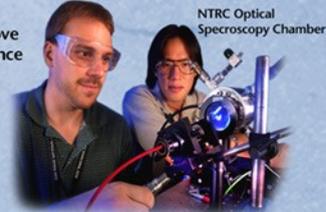
Objective

- Characterize optical spectra of spark plug arcs to evaluate the ignitability and erosion or age characteristics of spark plugs
- Characterize and measure spark plug erosion as a function of field-tested time
- Provide understanding of corrosion and erosion mechanisms of spark plugs in natural gas engine environments
- Provide design guidelines for ignition systems of Advanced Reciprocating Engine Systems
- Develop advanced alloys to improve the corrosion/erosion resistance and extend the lifetime of electrodes and spark plugs

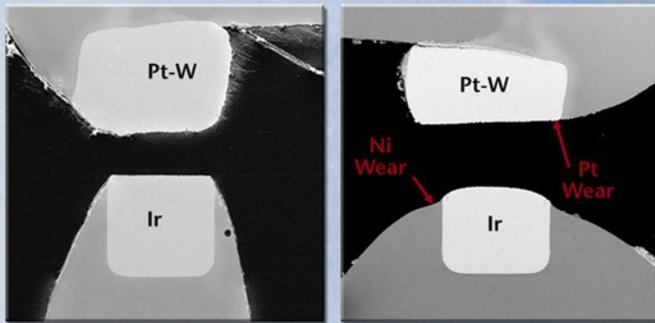
Integrated Approaches



- Develop diagnostic tools for measuring shot-to-shot erosion
- Optical spectroscopy analysis for field-tested spark plugs acquired from gas engine companies, i.e., Caterpillar, Cummins, and Waukesha
- Identification of erosion/corrosion mechanisms of ground and center electrodes via systematic optical and SEM analysis
- Develop advanced alloys to significantly improve spark plug reliability and extend life performance

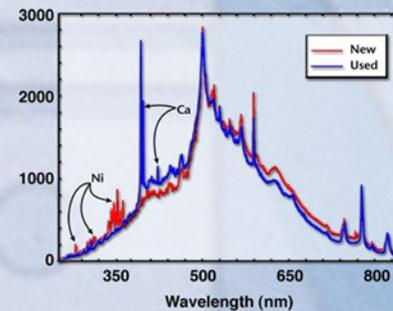


Spark Plug Erosion is Observable



The tips of the spark plugs wear away until the gap distance is too large for the plug to fire

Optical Spectroscopic Analysis Detects Chemicals During Spark Process



Test Chamber – 0-200 PSIG

- Ca from the engine oil
- No detection of Pt, W or Ir from electrode tips

Detection of Ni in new spark plug suggests the erosion of Ni-based electrode due to sputtering process

Ir Electrode Shows Glassy Phase and Cracking



SEM micrographs of Ir central electrode showing substantial formation of glassy phase enriched with Ca on electrode side surface (b) and intergranular cracking and Ir-Ni glassy phase formation on Ir tip insert surface (c).

Pt-W Electrode Shows Glass Phase and Cracking



SEM micrographs of Pt-W alloy ground electrode showing substantial formation of glassy phase enriched with Ca on electrode side surface (b) and crack generation and localized melting on Pt-W alloy tip insert surface (c).

Summary of Observations

- Pt and Ir tips are eroding but not sputtering
- Large amounts of Ca present around the tips
- Oxide scale containing Pt-W-Ca-O observed on both electrode side surfaces
- Periodic crack-lines formation due to localized material corrosion/erosion observed on Pt-alloy electrode tip surface after field service
- Substantial oxidation plus mud crack formation also observed on the Ir central electrode tip surface region
- There are metallic elements from the sputtered Ni-base electrode that deposit on the Ir and Pt surfaces and react with Ca and O producing a significant glassy phase (Ca-M-O) formation
- Generation and coalescence of intergranular cracks could accelerate the material erosion process of electrodes and further limit the lifetime of spark plugs

Conclusions – Erosion/Failure Mechanisms

- Sputtering of oxide scale containing Pt-W-Ca-O from Pt-W Insert
- Generation of coalescence of intergranular cracks for both the Pt-W and Ir inserts

Issues to be Investigated

- The evolution of intergranular cracks and formation of Ca-containing glasses in both Pt and Ir electrode as a function of field test time and engine environments
- Are they life limiting?
- The kinetics of crack generation and growth and its relationship to application environments
- The governing life limiting process of electrode and thus spark plugs
- A cooperative effort with engine companies has been proposed and will be carried out to systematically evaluate the above stated issues

Provide important guidelines for alloy development efforts

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