Mechanical Reliability of Piezo-Stack Actuators
(Agreement 13329)

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This presentation does not contain any proprietary or confidential information.
Outline

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Purpose of Work

• Contribute to the attainment of 55% thermal efficiency in HDD engines with concomitant reductions of NOx and PM.

• Develop and exploit advanced fuel injection strategies and adapt them to HDD engines.

• Adapt structural ceramic design methods to the design optimization (i.e., tensile stress minimization) of piezoceramic multilayer actuators (PMLAs).

Piezo-actuated fuel injector used in Ford 6.4L Power Stroke® (LDD) engine
Barriers

- Spray control of solenoid fuel injectors imprecise and limited; PMLAs can enable precise and complex fuel injection.
- NOx, PM, fuel consumption, and noise are too high in HDD engines; use of PMLAs in fuel injectors can reduce them all.
- PMLAs can be susceptible to fatigue and are brittle; the successful adaptation of structural ceramic design methods enables their management and predictable lifetime.

Piezoactuation enables:
- Rate shaping
- Control of both injection timing and fuel quantity control
• Measure and contrast mechanical properties of piezoceramics that are candidates for use in PMLAs.
• Measure response and reliability of PMLAs and link to measured piezoceramic properties (microscale/macroscale).
• Develop accelerated test methods that enable rapid and reliable qualification of PMLAs.
• Adapt to fuel injectors for HDD engines.
Performance Measures

- Use design sensitivity analysis with a PMLA to increase its survivability by 25% without compromise to needed operational total displacement and load bearing capability.
- Provide strength-limiting-flaw size distribution information to piezoceramic manufacturers to enable process modification that will increase material strength by 20%.
• Test facilities established to piezoelectrically and mechanically evaluate piezoceramic materials and PMLAs.
• Effects of electric field on strength of poled piezoceramic.
• Strength-limiting flaw types identified in tape-cast piezoceramics.
• Displacement changes interpreted and fast Fourier transform (FFT) analysis used to study dielectric and piezoelectric constant changes during $10^9$ cycle operation of a PMLA.

Electric field affects mechanical strength in poled piezoceramics
• An analysis method has the potential to be used with HDD engine fuel injectors to continuously diagnose changes in dielectric, piezoconstant, and displacement of a PMLA, and forewarn of PMLA mortality.

• Information about strength-limiting flaw distributions in commercial piezoceramics can be used by their manufacturers to modify their processing to reduce the maximum flaw size and increase strength.
Activities for Next Fiscal Year

- Develop design sensitivity model for PMLA.
- Further refine analysis of size-scaling and PMLA response and reliability.
- Complete development of accelerated test methods.
- Execute research as part of (anticipated) CRADA with Cummins, Inc.
Summary

• Confident utilization of PMLAs in HDD engine fuel injectors will be enabled and decrease fuel consumption rate.

• Characterizing, modeling, and linking microscale and macroscale performances of piezoceramics and PMLAs.

• Employ design sensitivity analysis with PMLAs.

• Manufacturers of piezoceramics will be able to increase material strength while end-users of PMLAs will be able to diagnose performance changes and predict end-of-life.

• Next year’s efforts to include:
  – Study of PMLA performance and size-scaling
  – Completion of accelerated test method development
  – Anticipated CRADA with Cummins, Inc.
