High Temperature Fuel Modulation for Improved Engine Performance

Alp Sehirlioglu
Department of Materials Science and Engineering
Case Western Reserve University
Active and Passive Vibration Control of Fan Blade Using Piezoceramics

Fuel modulation:
- Increased engine efficiency
- Decreased NO\textsubscript{x} gases

Coolant modulation:
Equivalent power can be obtained with a lower inlet temperature, thus less fuel

Noise minimization:
Fan, turbine, compressor, exhaust, combustor.

Atomizer:
Spray atomization is very important to reduce the fuel/air mixing time

Application:
Develop new materials and concepts that enable higher turbine engine operating temperatures

Benefits:
- Increased turbine engine operating temperature can dramatically increase fuel efficiency & reduce emissions
- Current DOD study shows only reasonable way to increase engine temperature is by advanced materials
- 2001 Stanford study shows a $1B/year fuel savings if engines run 1 degree C hotter

Properties that matter

- **Piezoelectric coefficients** ($d_{ijk}$)

$$D_i = d_{ijk} \sigma_{jk} \quad \varepsilon_{jk} = d_{ijk} E_i$$

- **Electromechanical coupling coefficients** ($k_{33}$, $k_{31}$, $k_p$, $k_t$)

$$k^2 = \frac{E l e E c M}{e cE h n}$$

- **Energy conversion efficiency**

- **AC and DC resistivity**
  - Material has to be insulating at high temperatures (DC)
  - Material should not heat up at high frequency loading (AC)

- **Coercive field** ($E_c$)
  - Electrical hardness, ability to apply higher negative bias for larger stroke, better ability to handle mechanical load
Fuel modulation

- Lean combustion: high-performance operation (increase efficiency, reduced emissions), lower stability (thermoacoustic instabilities).
- Large pressure oscillations due to instability: damage equipment, reduce efficiency, increase emissions, and blow out the flame. High-bandwidth fuel modulation for controlling combustion instabilities.
- Active combustion control require compact, robust, low-cost actuators that are capable of high-frequency operation.
- Piezoelectric and magnetostrictive materials, operation frequencies exceeding 1 kHz
  - Magnetostrictive actuators are larger, less technologically advanced, achieve narrower bandwidth, higher cost.
  - Piezoelectric actuators: large forces, high frequency.
- Stacks: To amplify the strain (0.1% per layer), decrease operating voltage.
- Other strain amplification (levers, bimorphs etc.), at the expense of force and more complex
- Pressure bias: Operation in compressive range.

The fundamental peak of the combustion instability was reduced by 30 dB, and the broadband sound pressure levels inside the combustor were reduced by 12 dB.

http://www.physikinstrumente.com

Other applications

**NASA space:** (Rodger Dyson)

Gas drilling:
- Drilling
- Acoustic borehole logging
- Ultrasonic flow meters,

Challenges:
- Increased pressures
- Increased temperatures resulting from increased depth.

**Smart Piezoelectric Damping Technology:**
Piezoelectric damping system for high temperature turbomachinery blade applications

In collaboration with Kirsten Duffy / GRC
Challenges

Piezoelectric Coefficient vs. Curie Temperature

Loss Tangent and ac Conductivity

High Field Properties and Leakage

Depoling Temperature vs. Curie Temperature

0% Bi >20μm

5% Bi <2μm

T_C

430

404
Piezoelectric Ceramics


H.C. Materials Corp.

Ternary Phase Diagram

$$\text{ABO}_3 = \text{BiInO}_3, \text{BiYbO}_3, \text{Bi(Zn,Zr)O}_3, \text{Bi(Zn,Ti)O}_3$$

Jacob Jones, Materials Science and Engineering, University of Florida
Weak Field – $\varepsilon_r$, $\tan\delta$ vs. $T$ @1kHz

![Graphs showing $\varepsilon_r$ and $\tan\delta$ vs. $T$ for different materials.]

- Except for Ta, all dopants increase $T_c$
- Acceptor doping of Ga, Mn lowers $\tan\delta$ by half
- At higher temperatures, Ga becomes lossy; Mn preferred for $\tan\delta$

<table>
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<th>$T_c$</th>
<th>RT $\tan\delta$</th>
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*PZT5A3 provided by Morgan Electroceramics
Actuation

• 5 plates electrically in parallel, physically in series
• Stack has multiplicative effect on strain with only ~5% loss
• Mechanical set-up to measure displacement as a function of stress, temperature, frequency and electric field

Working on decreasing the noise
Summary

• New piezoelectrics with enhanced properties and greater operating temperature have been developed.
• Properties of interest has been shown as a function of temperature.
• Basic stack actuators with low loss in total stroke has been produced.
• A new instrument has been build to measure the properties as a function temperature, stress, electric field and frequency.
• Blocking force has been measured.
• Improvements on the instrumentation will be finished before the submission of the final report.