In-Line Electromagnetic Actuator for Fuel Modulation

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Introduction

• Demand for Lower Emissions (LE) in Aircraft Gas-Turbine Engines – Lean Burn (LB).
• LB/LE combustors susceptible to thermo-acoustic instabilities.
• Utilize fuel modulating actuators to actively control instabilities.
• In-Line Electromagnetic Actuator (ILEM) fuel modulator conceptualized, prototype fabricated, and tested.
• ILEM fuel modulator tested up to 1.2 kHz with input fuel pressure of ~300 psia.
ILEM Fuel Modulator Description

- Normally open valve design.
- Magnetically actuated.
- Magnetic circuit - plunger moves to close valve when current applied to coil in order to minimize energy in the system.
- As plunger moves towards bottom cap valve closes partially.
ILEM Fuel Modulator Prototype

Fuel Inlet
Cantilever Spring
Wires Coil
Sliding Plunger
Magnetic Bottom Cap

Top Cap
Magnetic Sleeve Legs
Magnetic Sleeve
Outlet
Electrical Terminal
Test Setup

- Bench top tested using jet fuel.

Needle valve simulates injector

ILEM Control Unit

\[ V_{\text{ext}} \]

\[ V_{\text{drive}} \]

Zener Diode

BJT

\[ R_{\text{base}} \]
Test Conditions

- 300 psia inlet to ILEM
- Flow rate ~43 pounds per hour (PPH)
- Steady state measurements taken followed by measurements with the ILEM being driven from 100 Hz to 1200 Hz back to 100 Hz, in 100 Hz increments.
- Power supply voltage to the ILEM control unit circuit set at $V_{\text{ext}} = 4 \text{ V}$, $V_{\text{drive}} = 8 \text{ V}$ peak-to-peak.
180 Hz noise distortion at lower frequencies
Test Results Continued

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<th>P&lt;sub&gt;CNeedle&lt;/sub&gt; Dyn</th>
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<th>P&lt;sub&gt;C&lt;/sub&gt; Dyn (PSI)</th>
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Actuator Flow Number = ≈15.00
Needle Valve Flow Number = ≈2.50
Increasing Excitation Voltage

Goal: Increase the drive voltage to bring the plunger closer to the bottom cap and increase differential pressure (lower FN).

- Power supply voltage to the ILEM control unit circuit set at $V_{\text{ext}} = 4.5 \, \text{V}$, $V_{\text{drive}} = 8 \, \text{V peak-to-peak}$.

- Same inlet pressure and flow rate as multi-frequency testing above. (300 psia / 43 PPH)

- **Observation:** at lower frequencies the plunger would come in contact with the bottom cap – electromagnetic snap-in.

- Electromagnetic snap-in due to nonlinear electromagnetic force relation to the gap spacing vs linear restoring force from spring tethered to plunger:

  $$F \propto \frac{\mu_o A (NI)^2}{\text{gap}^2}$$

- When snap-in occurs the plunger is in intimate contact with the bottom cap – restricting flow.
Effect of Snap-In Phenomena

ILEM Off    ILEM On

Flow Rate (pph)

Pinlet ST (psi)

ILEM DP (psi)

Needle DP (psi)

FN ILEM (psi)

FN Needle (psi)

Time, sec

Time RMS=6.39, Mean=24.22

Time RMS=123.94, Mean=644.61

Time RMS=174.15, Mean=519.16

Time RMS=55.01, Mean=124.73

Time RMS=4.44, Mean=2.38

Time RMS=0.34, Mean=2.20
Discussion

• Achieved primary goal of demonstrating functional capabilities of ILEM actuator to modulate fuel at various frequencies.

• Optimum performance of the ILEM actuator was demonstrated from 600 Hz to 1200 Hz.

• Noise prevalent in system at 180 Hz, possibly coupling noise from the grid power.

• Below 600 Hz measured modulation was not strong enough to overcome noise in the system.
Discussion-2

• Settings for the ILEM control unit circuit have yet to be optimized.

• Test results presented above were taken with conservative drive voltages to ensure a complete set of data could be captured in limited test time.

• Initial explorations of higher drive voltages indicate full capability of the ILEM modulator untapped.
• Snap-in phenomenon demonstrates the electronics drive parameters can be further optimized.

• Minor modifications to design can improve performance and eliminate pull-in phenomenon
  » Add a non-magnetic spacer to the tip of the plunger.

• Snap-in phenomenon indicates ILEM modulator is tunable for different flow numbers.
  » Apply a DC current to the magnetic coil to bias the DC position of the plunger.
Conclusions & Future Work

- Demonstrated electromagnetic fuel modulator design capable of fuel modulation from 600 to 1200 Hz.
- Best response occurs near 600-700 Hz.
- Still a lot of room to improve performance by adjusting drive control electronics parameters.
- Future work will include optimizing drive voltages to increase differential pressure at ILEM outlet.
- Future work will explore variable tuning for desired flow number via application of DC current to preset plunger position.
- Non-magnetic spacer to be added to the plunger tip to prevent snap-in at lower frequencies.
Acknowledgements

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