# Smart Structures in Army Weapon Systems

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## DARPA Smart Structures Technology Interchange Meeting

Baltimore, Maryland

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**Jeff Vipperman** - University of Pittsburgh
**Chris Lavigna** - Techno Sciences, Inc.
**Richard Lyman** - Christensen Arms
**Jeff Paine** - Dynamic Structures and Materials

# Project Overview

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**Objective:** To develop novel enabling smart structures technology that can be used to improve Army fire control and weapon systems through structural vibration control.

**Application Form:** Roof mounted 0.50 cal CLAWS system on a HMMWV.

**Critical Issues:** Reducing dispersion and bias errors caused by vibrations in weapon systems will result in:

- increased standoff ranges
- reduced burst length
- minimized collateral damage

Vibrations appear as 1) gun barrel flexure and 2) total gun body motion due to recoil.

**Enabling Technologies:** This project focuses on two enabling technologies that can be applied to vibration suppression in weapon systems:

1) Smart composite gun barrels with imbedded sensors and actuators.

2) Smart vibration suppression mounts

# Project Schedule

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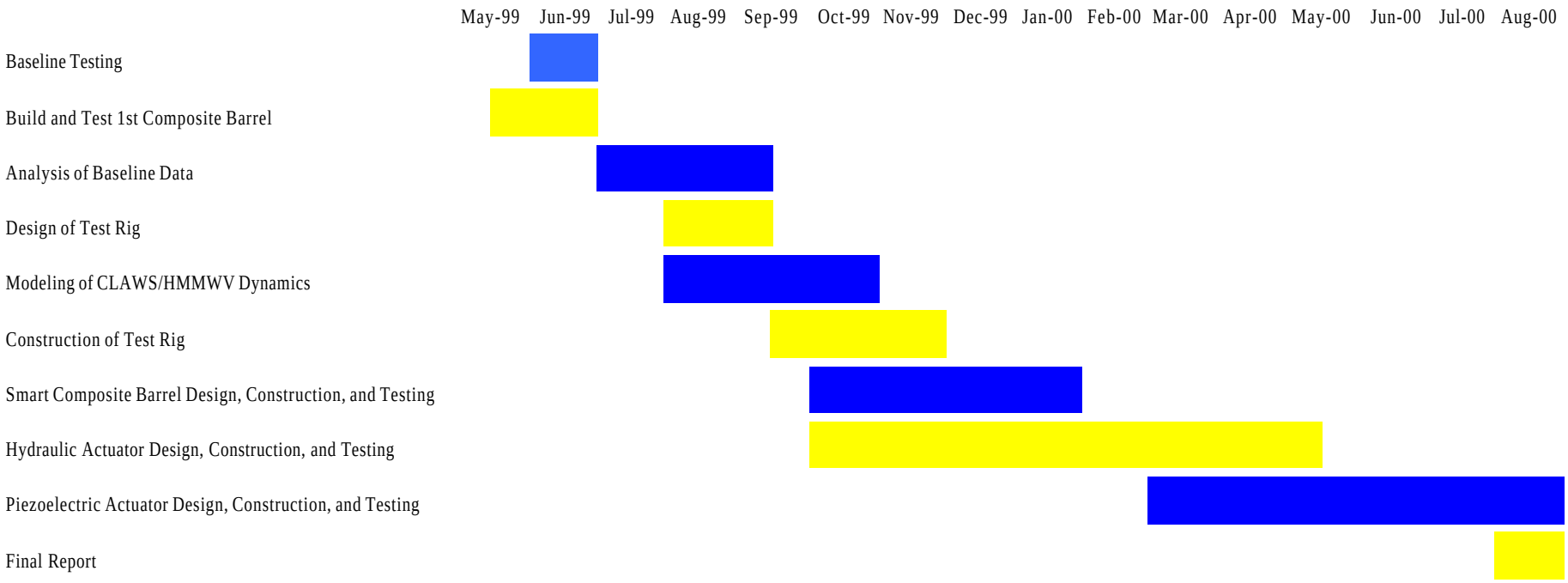

# Team Members

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**Technical Monitor:** **Advanced Drives and Weapons Stabilization Team of TACOM-ARDEC, Picatinny Arsenal** -- Michael Mattice

**Primary Contractor:** **Techno-Sciences, Inc.** -- Chris Lavigna
Baseline testing; imbedded sensor concepts for smart barrel

**Subcontractors:** **Christensen Arms** -- Richard Lyman
Smart barrel manufacture

**Dynamic Structures and Materials** -- Jeff Paine
Actuator development

**Kollmorgen Electro-Optical** -- Joe Gaetani
Interface concepts for stabilization and fire control system

**University of Pittsburgh, Mechanical Engineering Department**
William W. Clark, Jeffrey S. Vipperman, William S. Slaughter
Baseline testing, analysis and modeling; smart barrel concepts and testing; actuator development and testing

# Key Accomplishments

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- Live-fire testing of HMMWV/Claws with 0.50 gun system
  - Dynamics characterized and modeled
- Two (first-ever) composite 0.50 cal barrels built and tested
  - Smart barrel incorporates novel sensor concepts, including novel piezoelectric pressure sensor
  - Future potential for imbedded actuators using same composite technology in large gun tubes
- Semi-active vibration suppression concepts tested for Army weapon systems
  - Hydraulic semi-active actuator
  - Piezoelectric semi-active actuator

# Knowledge Gained and Lessons Learned

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- Weapon systems present a violent environment for smart structures technology (e.g. 6000 lb. dynamic loads, accelerations > 500g).
- For this application, an actuator requires maximum (> 3000 lbs.) and minimum (< 50 lbs.) forces and large stroke (~ 0.5 in) to be effective.
- Piezoelectric materials can be used to develop fast, low power, high range semi-active actuators (first prototype: 200-2300 lbs., 0.5-1W power requirement, 100Hz bandwidth)

  Potential Transitions:

  - Weapon systems
  - Helicopter seat mounts
  - Off-road vehicle suspensions
  - Self-powered variable dampers

# Integrated Control Technologies for Future Weapon Systems

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**Smart Barrel**

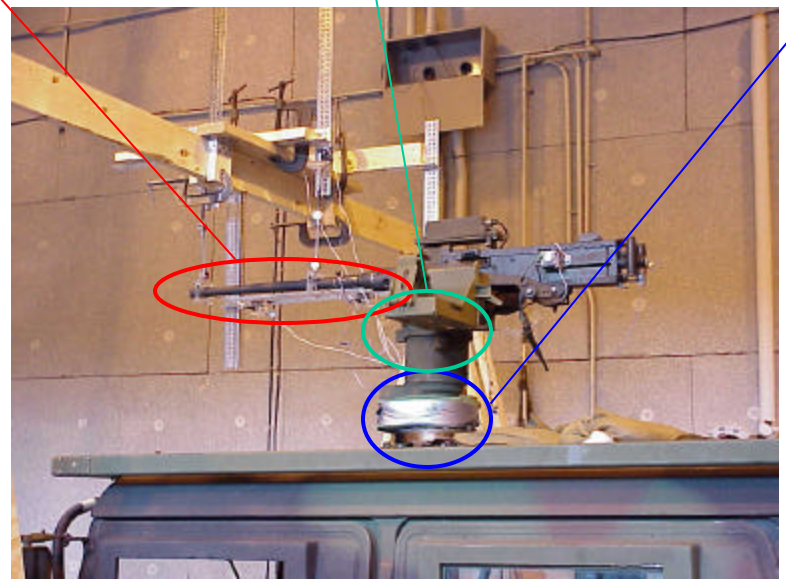
Imbedded Sensors and Actuators for fine dynamic compensation and minor pointing adjustments

**Stabilized Gun Actuators**

Coarse weapon pointing; low frequency dynamic compensation and stabilization

**Smart Suppression Mount**

Vibration suppression; facilitates integration of weapon and vehicle systems



# Fabrication of Smart Barrel Prototype
## (Composite barrel was built by Christensen Arms)

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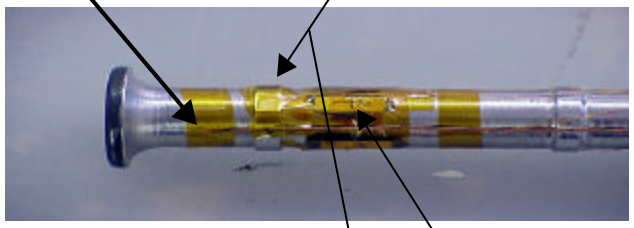
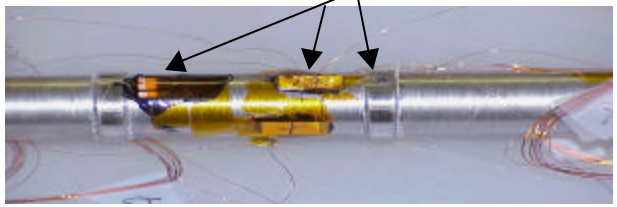
Schematic of Smart (Sensing) Barrel Prototype

Embedded Thermocouple

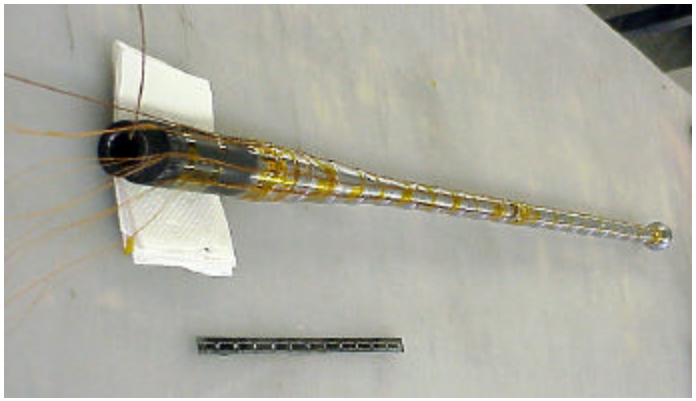
Novel PZT Pressure Transducers



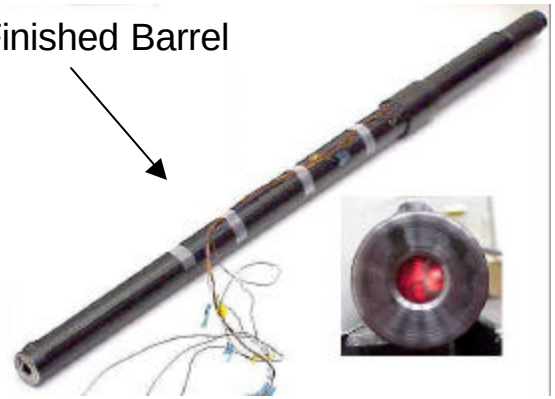
Strain Gages



Fully-Instrumented Barrel Prior to Composite Layup



Finished Barrel



# Applications of Smart Barrel

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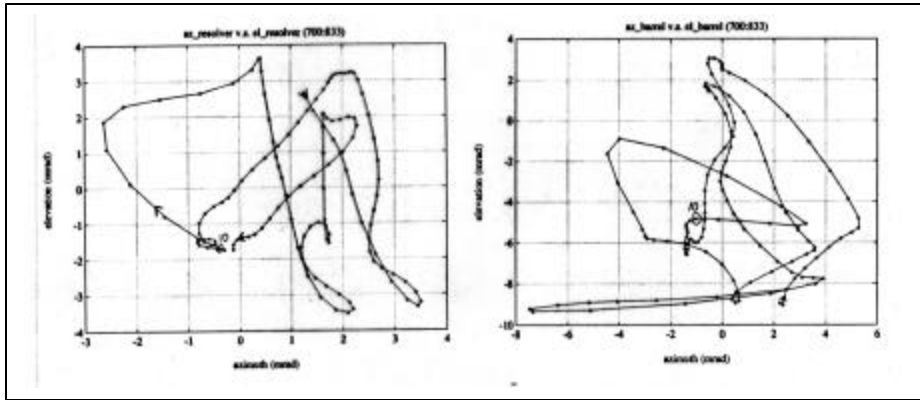
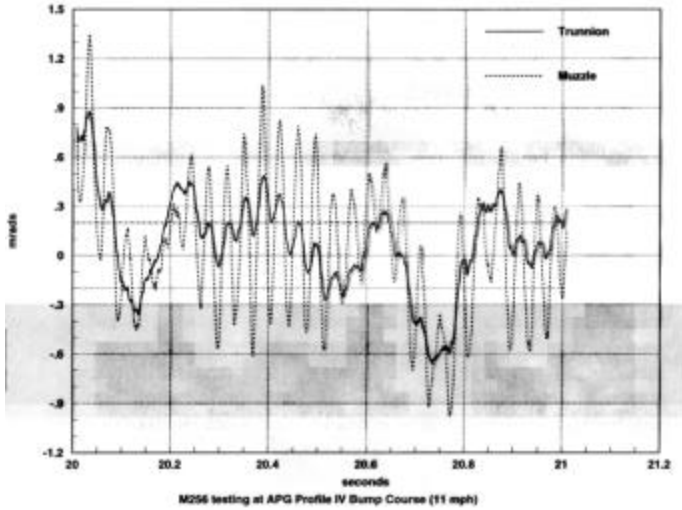
## 30 mm M230 Gun Turret on Appache Helicopter

Barrel deflection during firing due to:
Rigid body motion  Gun tube bending



## M256 Gun Tube Bending on M1A1 Tank

Rigid body = solid line
Tube flexure = dashed line



# Baseline Testing of CLAWS/HMMWV Dynamics

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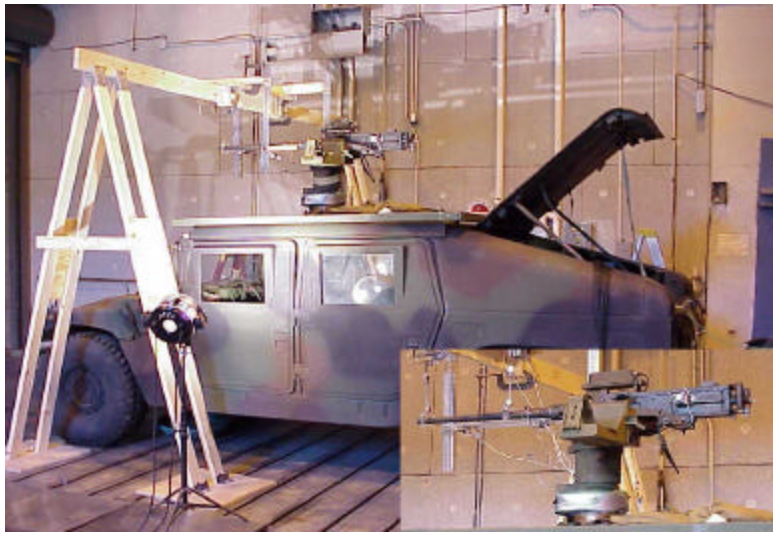
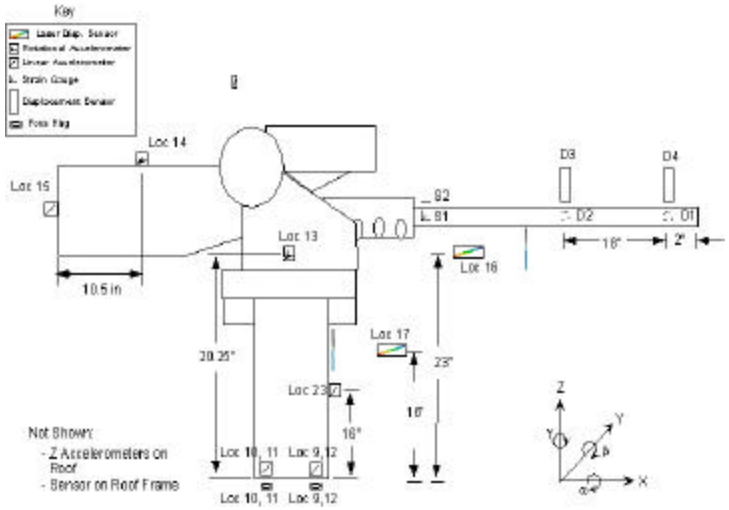
- Testing of 50 cal gun in CLAWS mounted on HMMWV
- Live-fire testing at Picatinny Arsenal
- 40 different tests: Single Shot and Burst
- Data included:  accelerations; forces; gun barrel displacement, strain, pressure, and temperature; and high-speed video.
- Gun barrel azimuth angles of 0º and 90º





# Baseline Testing of CLAWS/HMMWV Dynamics: Sample Data

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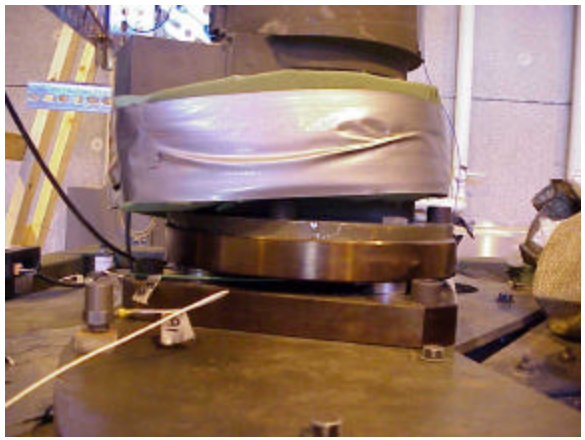
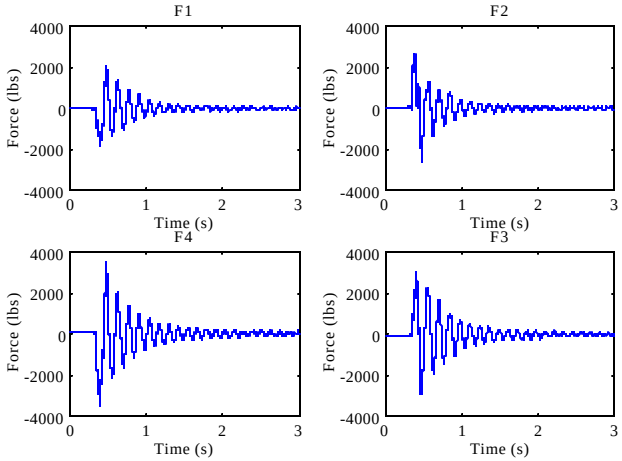
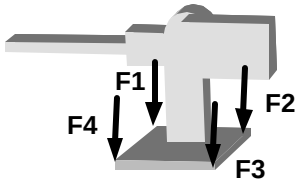
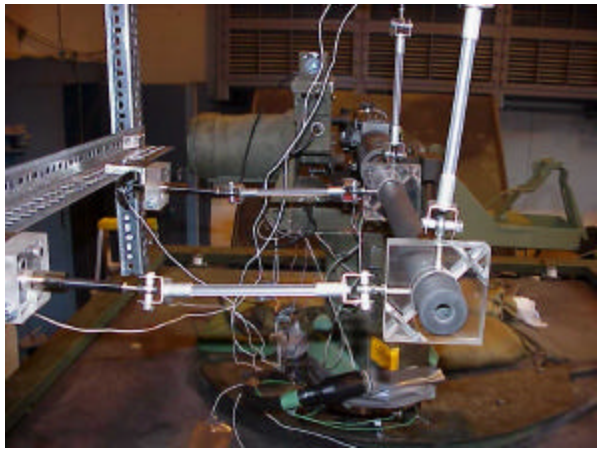
## Force Measurement at CLAWS Mount

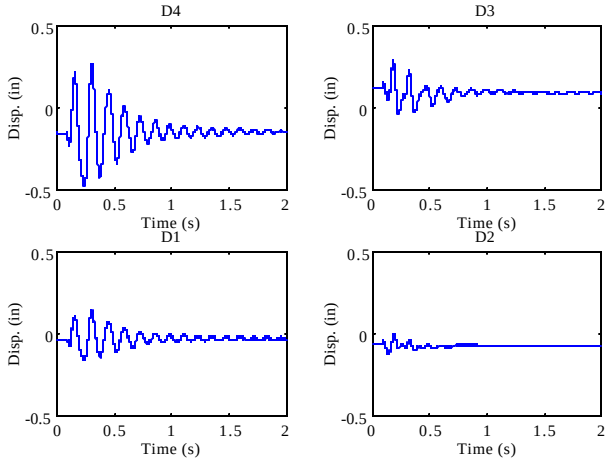


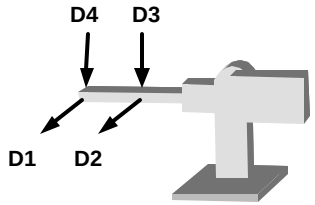



## Gun Barrel Displacement Measurement





# Semi-Active Hydraulic Actuator

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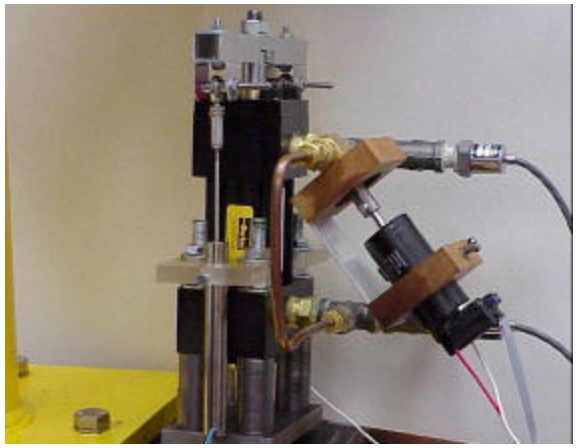
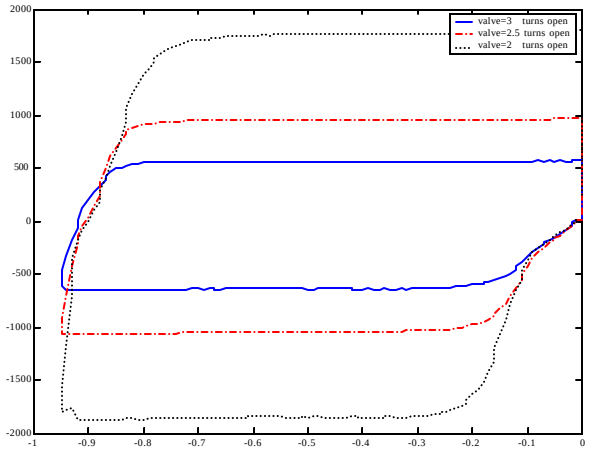





Characteristics:

Max Force = more than 2000lb
Min Force = 50lb
Bandwidth = 0 ~ 25Hz

Cylinder Dimensions:

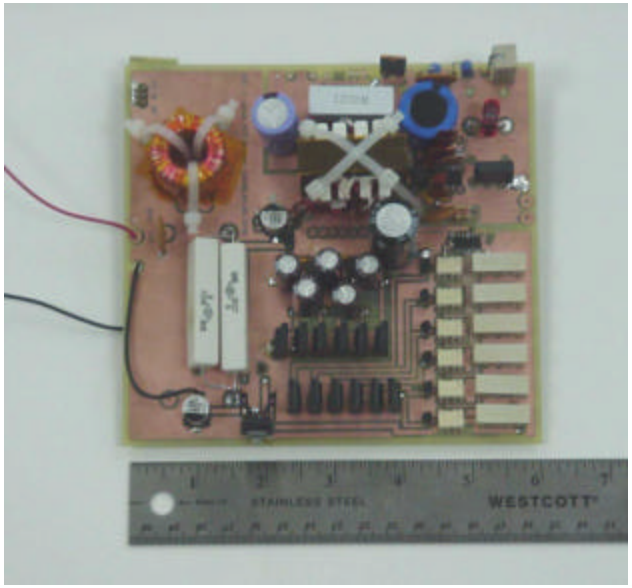
Piston Area : 1.5in bore
Valve Area : .187in, 0.25in (pipe)

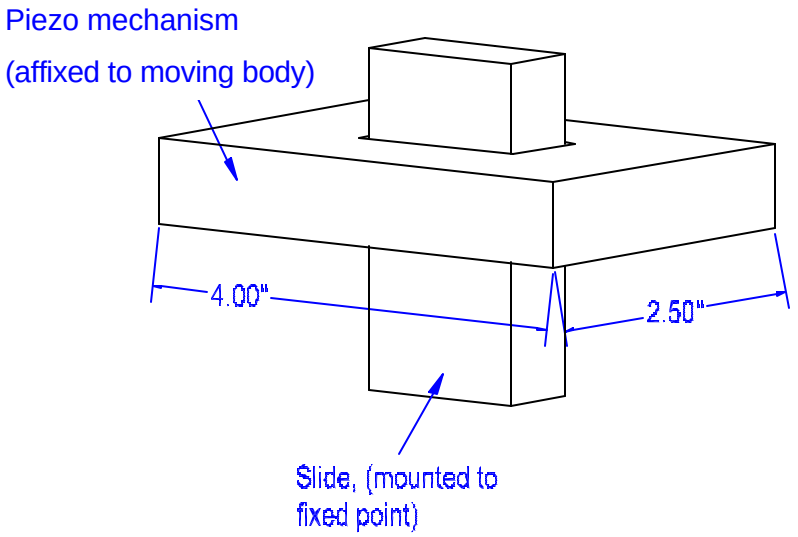
Operating Pressure: 600~800 PSI

# Semi-Active Piezoelectric Actuator

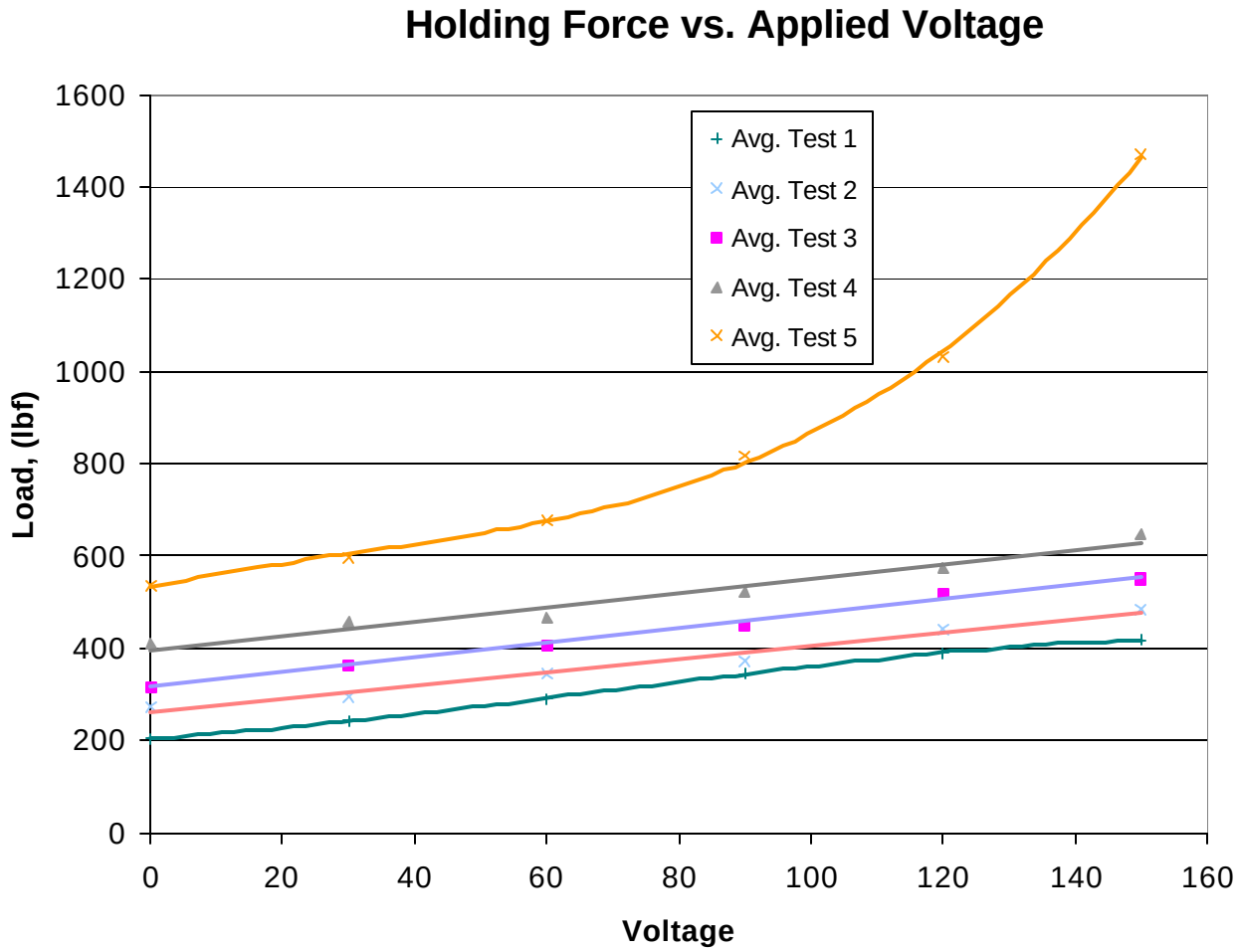
dsm
Dynamic Structures & Materials, LLC

- Piezo driven mechanism
- Capable of static and dynamic operation
- Custom-built six-setting control electronics
- Infinitely adjustable starting point
- DC operation ensures low power consumption

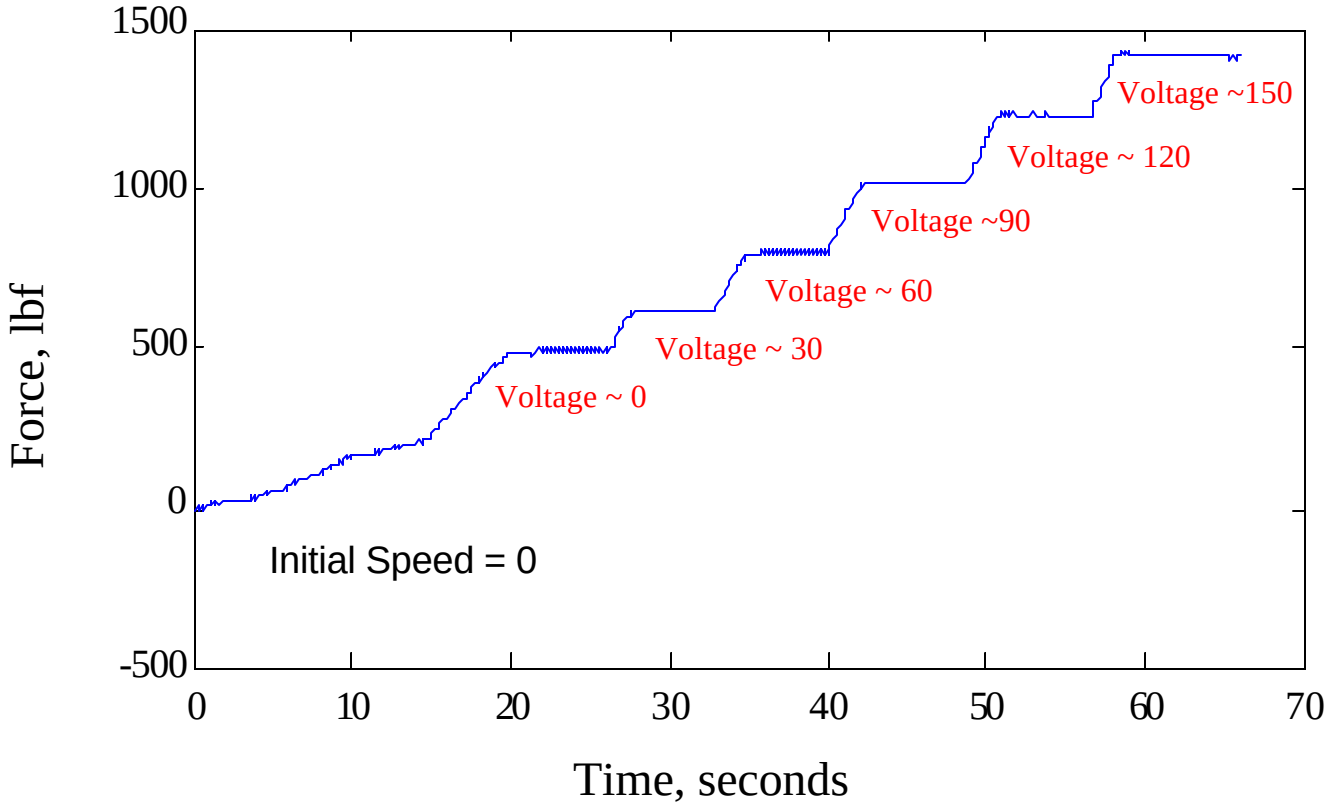


# Piezo Actuator -- Static Test Data



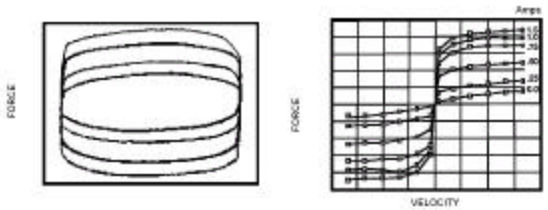
# Piezo Actuator -- Dynamic Test Data



# Comparison of Semi-Active Actuators

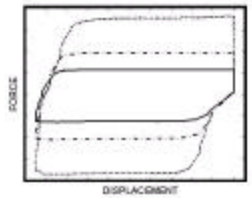
dsm
Dynamic Structures & Materials, LLC

| | MR Fluid* | Hydraulic | Piezoelectric# |
|---|---|---|---|
| Dimensions | Length 8.5in<br>Diameter 1.5in | Length 6.25 in<br>Width 4.5 in<br>Height 8 in | Length 4 in<br>Width 2.5 in<br>Height 2.5 in |
| Stroke | 2 in | 1.5 in | 0.5 in |
| Max. Force | 300 lbs | >2,000 lbs | ~2,300 lbs |
| Power | 15 W | 0 - 2 W | <0.5 W |

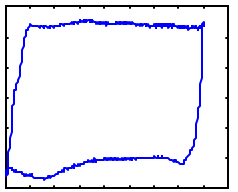


MR Fluid

*Lord Corporation Damper



Hydraulic Cylinder



Piezoelectric Actuator

#DSM Actuator