ELECTROMECHANICAL ACTUATION FOR LAUNCH VEHICLES

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37th AIAA/ASME/SAE/ASEE Joint Propulsion Conference
Salt Lake City, Utah
July 10, 2001
This paper describes recent developments in Electromechanical Actuation applied to Launch Vehicles. The following topics are discussed:

- Electromechanical (EM) Actuation System Design
- Comparison of Electromechanical and Electrohydraulic Actuation Systems
- High Power EM Thrust Vector Control (TVC) Systems
- Redundant EM TVC Systems
- Propellant Valve Electromechanical Actuation
Electromechanical TVC Actuation System
Electromechanical Servoactuator System

Permanent Magnet Brushless Motor
Sinusoidal Motor Drive

MOOG
Comparison of EM and EH Actuation Systems

_advantages of conventional electrohydraulic systems_

- Mature Technology
- High Reliability
- Can Use Relief Valves to Limit Piston Force
  - Effective to Handle Impulse Load
- Continuous Stall Torque Capability
- High Acceleration Capability
- No EMI Generation
- Simple, Low Power Electronics
- Mature Redundancy Implementation
Comparison of EM and EH Actuation Systems

Advantages of Electromechanical Systems

- Excellent Long-Term Storability
- Easy Checkout
- Easy Installation
- Low Maintenance
- Minimal Operations Cost
- Low Quiescent Power
- No Fluid Leakage
- No Concern for Fluid Contamination
- High Reliability
- Lower Weight than Hydraulic Blowdown TVC Systems
Limitation of EM Actuation Systems

Typical EM System Frequency Response Limits
38 HP EM TVC ACTUATOR Dual Torque-Summed Motors

Output Travel……… +/- 5.5 in
Stall Force ……….. 55,000 lb
Rated Power………. 38 HP
   Output Force…….. 48,000 lb
   Output Velocity….. 5.2 in/sec
Impulse Load ……. 100,000 lb
Acceleration………60 in/sec^2
Duty Cycle………..10 min
Average Load… 15,000 lb
Supply Voltage….270 VDC

Full Performance with one motor
38 HP EM Actuation System

Force-Velocity Test Data On SSME Test Fixture

![Graph showing force-velocity test data on SSME test fixture](image)
Frequency Response Test Data On SSME Simulator
Load Position Response (+/- 2 % COMMAND)
Frequency Response Test Data On SSME Simulator

Load Position Response (+/- 5 % Command)
◆ Controller Critical to Performance of EM Systems

◆ Breadboard Controller Used to Demonstrate 38 HP EM TVC System

◆ Development of Flight Worthy High Power EM Controller
Moog DSP-Based Digital Controller

- Digital Loop Closure
- IGBT Power Stage
- 320 VDC Maximum Supply Voltage
- 200 Amps Peak Motor Phase Current
- Vector Control / Sinusoidal Motor Drive
- Demonstrated with a 20 HP EM TVC Actuator
### Two TVC Actuators Have Been Demonstrated

<table>
<thead>
<tr>
<th></th>
<th>12 HP</th>
<th>21 HP</th>
<th>---</th>
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<tbody>
<tr>
<td>Stall Force (lb)</td>
<td>4600</td>
<td>31,000</td>
<td>Brushless PM Motor</td>
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<tr>
<td>Stroke (in)</td>
<td>+/- 1.92</td>
<td>+/- 1.5</td>
<td>Ballscrew</td>
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<tr>
<td>Length (in)</td>
<td>15.5</td>
<td>17.0</td>
<td>LVDT</td>
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<tr>
<td>Power Point</td>
<td></td>
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<tr>
<td>Velocity (in/sec)</td>
<td>20</td>
<td>5.85</td>
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<tr>
<td>Force (lb)</td>
<td>4000</td>
<td>24,000</td>
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<tr>
<td>Weight (lb)</td>
<td>16</td>
<td>75</td>
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</tr>
<tr>
<td>Voltage (VDC)</td>
<td>280</td>
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Upper Stage Redundant EM TVC Systems

- Flight Proven
- Active-Standby Redundancy
- Full Performance with one motor operating
- Six-Step Motor Drive
## Upper Stage Redundant EM TVC Systems

### Typical Performance Summary

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Stroke</td>
<td>+/- 0.75 in</td>
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<tr>
<td>Stall Force</td>
<td>2000 lb</td>
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<tr>
<td>No-load Velocity</td>
<td>3.0 in/sec</td>
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<td>Output Power</td>
<td>0.4 HP</td>
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<tr>
<td>Frequency Response</td>
<td>90 deg phase @ 4.3 Hz</td>
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<tr>
<td>Actuator Length</td>
<td>23.25 in</td>
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<tr>
<td>Supply Voltage</td>
<td>28 VDC</td>
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<tr>
<td>Electrical Interface</td>
<td>MIL-STD-1553</td>
</tr>
<tr>
<td>Actuator Weight</td>
<td>17 lb each</td>
</tr>
<tr>
<td>Controller Weight</td>
<td>27 lb</td>
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</table>
Upper Stage TVC System Block Diagram

Active-Standby Redundancy
Full Performance With One Motor Operating
Propellant Valve EM Actuation Systems

- Dual Redundant Brushless Motors
- Harmonic Drive Provides Rotary Output
- Redundant Controller

Typical Performance
Stroke………………+/- 70 deg
Output Power.........0.05 HP
  Velocity.........340 deg/sec
  Torque…………..60 in-lb
Actuator Weight……8.2 lb
Controller Weight….21.3 lb
Voltage ..............28 VDC
Summary

- Electromechanical Actuation is a Reality for Launch Vehicles
  - **Flight Proven** EM TVC Systems on Upper Stages
- High Power Applications (Booster TVC Systems)
  - EM Actuation is a Viable Alternative to Electrohydraulic Actuation
  - High Power EM TVC Systems are **Flight Ready**
  - EM TVC Systems Offer the Potential of:
    - Lower Life Cycle Cost
    - Lower Weight