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
Comparison of EM and EH Actuation Systems

要点

- 成熟的技术
- 高可靠性
- 可使用释放阀限制活塞力
  - 有效处理冲击载荷
- 持续的空转扭矩能力
- 高加速度能力
- 无EMI生成
- 简单，低功率电子设备
- 成熟的冗余实施
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

![Graph showing frequency response limits for EM systems. The graph plots amplitude (%) against frequency (Hz). There are two curves: one for voltage limit and one for current limit.]
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 relationship with test data points and annotations]
Frequency Response Test Data On SSME Simulator
Load Position Response (+/- 2 % COMMAND)
38 HP EM Actuation System

Frequency Response Test Data On SSME Simulator
Load Position Response (+/- 5 % Command)

![Graph showing frequency response data with amplitude ratio and phase lag over frequency.](image-url)
Controller

- 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
# EM TVC Actuators For Large Solid Rocket Motors

## Two TVC Actuators Have Been Demonstrated

<table>
<thead>
<tr>
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<th>12 HP</th>
<th>21 HP</th>
<th>---</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stall Force (lb)</td>
<td>4600</td>
<td>31,000</td>
<td>--- Brushless PM Motor</td>
</tr>
<tr>
<td>Stroke (in)</td>
<td>+/- 1.92</td>
<td>+/- 1.5</td>
<td>--- Ballscrew</td>
</tr>
<tr>
<td>Length (in)</td>
<td>15.5</td>
<td>17.0</td>
<td>--- LVDT</td>
</tr>
<tr>
<td>Power Point</td>
<td></td>
<td></td>
<td></td>
</tr>
<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>
<td></td>
</tr>
<tr>
<td>Voltage (VDC)</td>
<td>280</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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<tr>
<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>
</tr>
<tr>
<td>Supply Voltage</td>
<td>28 VDC</td>
</tr>
<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>
</tr>
</tbody>
</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
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