Benefits of an Active Recoil Control System

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Agenda

• Recoil of Large Caliber Weapons
• Active Recoil
• Active Recoil applied to Soft recoil
• ADIM: A Case Study
• Conclusion
• Recoil systems are designed to dissipate a short duration firing impulse over a greater time and distance.
• Distributing the firing load reduces the impulse imparted to the supporting structure.

• Traditional recoil systems are optimized for the maximum weapon impulse.
• Limited compensation is possible at the cost of added complexity (i.e. elevation compensation).
• Most variables leading to atypical firing impulses are unaccounted for, including:
  – Propellant temperature
  – Munition lot variations
  – Lesser charge/increment fires
  – Hydraulic fluid properties (viscosity)
  – Manufacturing tolerances of the recoil mechanisms

• This results in underutilization of the available recoil stroke for most fires.
What is Active Recoil?

- Active recoil uses feedback from sensors to control the recoil system in real time.
- By controlling the recoil forces the available recoil length can be fully utilized resulting in reduced impulses transmitted to the support structure.
- At reduced charges/increments the optimization is more dramatic.

![Diagram showing comparison between traditional and active recoil systems](image-url)
Possible Active Recoil Technologies

1. Variable Viscosity Fluid
   - Magnetorheological
   - Electrorheological

2. Variable Orifice Valve

3. Electric Motor

4. Mechanical Brake
   - Eddy Current
   - Friction Disc
   - Hysteresis
   - Magnetic Particle

Should Fail Safe!
Where does active recoil make sense?

- Active Recoil Applied to Traditional Recoil
  - Potential Benefits
    - Utilize the entire recoil stroke for all charges/increments
    - Perform elevation compensation with active recoil device
    - Simplify recoil buffer
    - Loosen manufacturing tolerances
    - Perform diagnostics/prognostics on recoil components
    - Increase fatigue life of structure
  - Drawbacks
    - Does not improve force curve for max firing impulse
    - Support structure must still be designed to handle max firing load
    - Requires power
  - Conclusion
    - Historically, the sensors and processing hardware required to implement active recoil produced marginal benefits for the cost
    - Given modern technologies, it may make sense to revisit active recoil

What About Soft Recoil?
• Benefits
  – For similar recoil masses, initial recoil velocity in traditional recoil is ~twice that of soft recoil.
  – Recoil stroke can be shortened or recoil force can be reduced.
Employment of Soft Recoil in Modern Weapons

**Experimental**
- XM204 105mm Howitzer
  - US ARMY
  - 1906
- ATLAS 105mm Howitzer
  - US ARMY
  - 1966
- Hawkeye 105mm Howitzer
  - Mandus Group RIA
  - 1970
- ADIM 81mm Mortar
  - US ARMY
  - 1975

**Fielded**
- Mountain Gun 65mm Howitzer
  - France
  - 1997
- MK-19 40mm Grenade Launcher
  - US NAVY
  - 2006
- 2B9 Vasilek 82mm Mortar
  - USSR
  - 1975
- ADIM 81mm Mortar
  - US ARMY
  - 2011
- 2B9 Vasilek 82mm Mortar
  - USSR
  - 2013
Soft Recoil Challenges Solved with Active Recoil

<table>
<thead>
<tr>
<th>Ignition Timing</th>
<th>Impulse</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Soft Recoil</strong></td>
<td>![Graph showing Ignition Timing]</td>
</tr>
<tr>
<td>![Graph showing Ignition Timing]</td>
<td>![Graph showing Impulse]</td>
</tr>
<tr>
<td>![Graph showing Soft Recoil with Active Recoil]</td>
<td>![Graph showing Soft Recoil with Active Recoil]</td>
</tr>
</tbody>
</table>

*Must know prior to firing*
Automated Direct/Indirect fire Mortar (ADIM)

### Active + Soft Recoil

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammunition Caliber</td>
<td>81</td>
<td>mm</td>
</tr>
<tr>
<td>Ammo Capacity</td>
<td>20</td>
<td>rounds</td>
</tr>
<tr>
<td>Range</td>
<td>300-6300</td>
<td>m</td>
</tr>
<tr>
<td>Traverse</td>
<td>360 cont.</td>
<td>degrees</td>
</tr>
<tr>
<td>Elevation</td>
<td>-3 to 85</td>
<td>degrees</td>
</tr>
<tr>
<td>Weight</td>
<td>~2300</td>
<td>lbs</td>
</tr>
<tr>
<td>Recoil Force</td>
<td>&lt;10,000</td>
<td>lbf</td>
</tr>
<tr>
<td>Recoil Force (w/ Active Recoil)</td>
<td>&lt;2,000</td>
<td>lbf</td>
</tr>
</tbody>
</table>

![Diagram of ADIM with labeled components: Encoder, Controller, Brake]
### ADIM Active Recoil Brake

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max braking force</td>
<td>~1700</td>
<td>lb</td>
</tr>
<tr>
<td>Max Velocity</td>
<td>49.2</td>
<td>ft/s</td>
</tr>
<tr>
<td>Brake On Time</td>
<td>&lt;1</td>
<td>ms</td>
</tr>
<tr>
<td>Brake Off Time</td>
<td>~45</td>
<td>ms</td>
</tr>
<tr>
<td>Release Current</td>
<td>~10</td>
<td>A</td>
</tr>
</tbody>
</table>
Active Recoil System

Position Sensor → Controller → Brake

- Position Data
- Status Information
- Electrical Current

Fire

Send Lookup Tables
Send Fire Command
Controller

Start

Release Brake & Fire

Get Recoil Position & Velocity

Complete?

Yes

Forward

Direction

Rearward

Calculate Forward Setpoints

Engage Brake

End

Calculate Recoil Setpoints

Execute Control Loops
Control System Variables
• Controlled Variables
  – Solenoid Current
  – Recoil velocity
• Disturbance Variables
  – Firing Impulse
  – Passive Recoil Force
• Manipulated Variables
  – Solenoid current
ADIM's employment of Soft Recoil combined with Active Recoil

Charge 4

No Braking

Recoil Force

Encoder

Recoil Brake

Click to play
ADIM’s employment of Soft Recoil combined with Active Recoil

- **Charge 4**
- Braking on recoil stroke

**Recoil Force**
- 10,000
- 2,000
- 0

**Encoder**

**Recoil Brake**

Click to play
ADIM’s employment of Soft Recoil combined with Active Recoil

- **Charge 3**
  - No Braking
  - Recoil Force
    - 10,000
    - 2,000
    - 0

**Encoder**

**Recoil Brake**
ADIM’s employment of Soft Recoil combined with Active Recoil

Charge 3

Recoil Force

0
2,000
10,000

Braking on forward stroke

Encoder

Recoil Brake

Click to play
ADIM’s employment of Soft Recoil combined with Active Recoil

Charge 3

Braking on forward & recoil stroke

Encoder
Recoil Brake

Recoil Force

Charge 3

Position [m]

Charge 3

Time [s]
Conclusion

• Active recoil on ADIM prototype
  – Reduction of forces
  – Improved handling of variations
  – Going forward

• Future of Active Recoil
  – More viable than in the past
  – Application to other weapon systems

• Questions?


