US Navy Railgun and LASER Weapon System Intro and Power Requirements

14th Directed Energy Test & Evaluation Workshop
12-14 May 2015

CDR Jason Fox, USN
- Program Manager, PMS-405
  Directed Energy & Electric Weapon Systems
- Deputy Chief Technology Officer, NAVSEA HQ;
  Group Head, NAVSEA 05T
- Chief of Staff, NAVSEA 05 (NAVSEA CHENG)
Overview

• Railgun / Solid State Laser Overview
• Power Response: An Analogous Situation
• Energy Storage and Power Response
• Future Needs: Energy Storage
• Conclusions
Railgun Intro
How Railgun Works

Operating Principle

1. Electrical energy stored in capacitor bank
2. Switch closes, current flows through cables, rails & armature
3. Force from magnetic field and armature current pushes projectile down barrel
4. Sabot and armature discards

Cross-Section

Lorentz Force = Current (J) x Magnetic Field (B)
or
Lorentz Force = 1/2 Inductance Gradient (L') * Current (I)^2

Composite Wrap
Railgun Operational Impact

- **Wide Area Coverage**
  - Increased speed to target
  - 200+ NM

- **Accelerates operational tempo**
  - Faster attrition of enemy personnel and equipment
  - Operation timeline shifts left

- **Reduces Cost per Kill**
  - Lower Unit Cost
  - Lower handling cost

- **Enhances Safety**
  - No risk of sympathetic detonation
  - Simplified storage, transportation and replenishment
  - Reduced collateral damage
  - No unexploded ordnance on battlefield

- **Reduces Logistics**
  - Eliminates gun powder trail
  - Deep magazines

- **Multi-Mission Capability**
  - Surface Warfare
  - Missile Defense
  - Long Range Fires
  - Direct Fire
  - ASuW

Multi-Mission Capable for Offense and Defense
Railgun Development

Technology Development (ONR)
- Launcher
- Energy Storage
- Pulse Forming Network
- HVP
- Gun Mount

Technology Demonstrations (SCO, NAVSEA, ONR)
- JHSV Demo
- Maritime Specific Engineering
  - GPS Targeting
- Hardware
- Expertise
- Software
- Program Mgmt
- Contracts

Closed-Loop Fire Control
- Stressing Missile Threats

System Acquisition

System Deployment
- Multi-use Modular Railgun System
- US Navy Combatant
- Land Defense

Multiple Deployment Options

Land Defense Demo
Kinetic Energy Conversion
Railgun System Integration

MULTIMISSIONS
- AAW
- ASuW
- NSFS

LETALITY AND MISSION EFFECTIVENESS

MANUFACTURABILITY - OPERABILITY - RELIABILITY - MAINTAINABILITY - SUSTAINABILITY

\[ P_k = P_h \cdot P_{d/h} \cdot P_{k/d} \]
Advanced Power/Energy Systems

High Density Power Electronics

- Charging Power Supplies for Advanced Energy Systems
- Converting Ship's Power to High Voltage for Electric Weapons
- Supports Electric Drive, Railguns, Lasers & Radars

Battery Energy Storage

- Energy Storage to buffer Prime Generators
- Ready Reserve Energy for response to “quick” threats
- Requires close Ship Safety Design, Test & Monitoring

Pulsed Forming Network

- Capacitor based PFN
- Higher Energy Density lowers shipboard volume/footprint
- Rep rate operation & thermal management

System / Ship Integration

- Dynamic power sharing across platform
- Designing with Space and Weight Constraints
- Assessing Thermal and EM Field management
Laser Intro
Meet the Challenges facing the Navy

• Defeat Anti-access strategies that utilize asymmetric threats
  • Potential adversaries threatening to restrict Navy freedom to operate
  • Logistics & cost of using $3M weapons against $50k threat
  • Directed Energy puts us on the right side of the “cost curve”

• Expand magazine depth
  • Only limited by fuel onboard
  • Reduce at-sea weapons resupply

• Enhance ROE capabilities
  • Enable Real-Time Combat ID & Intent determination
  • Decrease battlespace
  • Speed, range, accuracy, maritime environment

High Energy Laser address existing Mission Requirements/Gaps.
Laser Weapon System
AN/SEQ-3 (XN-1) Timeline

Proof of Concept

Maritime

Maritime Dynamic

US Combatant

Testbed

Prototype

Deployment

2009

2010

2011

2012

2014

• 5/5 UAV engagements
• Commercial welding laser proof of concept

• 4/4 UAV engagements
• ISR dazzle & destroy
• Small boat negation

• Dynamic Tracking at sea
• Combat ID

• Operate from USS DEWEY fantail
• 3/3 UAV engagements
• Long-range Combat ID

• Deploy aboard USS PONCE
• Upgraded lasers, sensors
• CONOPS, Tactics

Successful Prototyping – From the Lab to the Fleet
Solid State Laser – Quick Reaction Capability
AN/SEQ-3(XN-1) Laser Weapon System (LaWS)

Laser Weapon System
Integrated with CIWS and Commercial Radars

Deployed October 2014: USS PONCE

- Risk reduction for future program of record
- Test feasibility of Laser Weapons in a harsh operational environment

- Solid State Laser – Quick Reaction Capability
  - AN/SEQ-3(XN-1) Laser Weapon System (LaWS)

Long Range LOS/Optical
Air Target ID, Defeat & BDA

Close & Medium Range
High Resolution Optical
ID, Defeat & BDA

COUNTER UAV
COUNTER ISR

COUNTER SMALL BOAT
Energy Storage & Power Response
Power Response: An Analogous Situation...

Images from Rego Apps; Closed Road, Professional Drivers
Instant vs. Sustained Power...

At first the Tesla pulls out handily... But the Lamborghini pulls ahead...

Instantaneous, on demand power; No transient issues

Sustained high power capability; Shift and Engine Power Buildup until moving

In the end, we desire both to enable highly functioning, highly transient, continuous operations.

Images from Rego Apps; Closed Road, Professional Drivers
PORSCHE 918
887 HP/944 lb-ft Torque
- 4.6L V8-608 HP
- 2 Electric Motors -279 HP
6.8 kWh Lithium Ion Battery
0-60: 2.4 Sec; Top Speed:210 MPH
24 MPG - Highway
• How do we get a cross of the Lamborghini and the Tesla?

• For DEWs:
  – Instant response of the battery
  – Wide powerband of a gas turbine or diesel
  – Energy density and content of the fuel tank

• Storage is finite; fuel can provide a much greater duration of operation

• Integrated storage (i.e. batteries) enables optimal use of the prime movers
Why Batteries: Don’t Ships Have Lots of Power?

DDG-51: ~9MW installed electric power

DDG-1000: ~78MW installed electric power

Not everything can be used/accessed by the ship – especially one load at a time!!
Aerodynamic couple in two-spool GTG makes transient concerns greater; however available large GTGs all use this architecture.
DEW Power Profile Options

- Constant Power
- Constant Current
- Stepped Constant Current

**Transients?**

- DEW load profiles are highly transient
- Rapid pick up and drop of load
- Creates substantial variation in GTG Loading, and subsequent thermal and electrical quality issues
- Some loads can be much noisier/faster varying dynamics!

Operations can turn into hundreds of accept and drop load scenarios for even short engagements
Future Operational Mode

Optimize storage buffering prime movers to enable continuous DEW operations with minimal effect on engine mechanicals and power quality…
Li-ion Baggage...

787 APU Battery (NTSB.gov)

EV Fires (NFPA.org)

Consumer Electronics (wired.com)

Li-ion Cargo (NTSB.gov)
Safety is Paramount

• Chemistry Selection
• Engineering design and controls
• Abusive testing and mitigations
• Unique NAVSEA 9310, MIL-882 and SG-270 analyses and safety packages
LFP Safety: Heat Release Under Abuse/Failure

LFP Minimal Heat Release at Elevated Temps

Electrolyte, separator and negative electrode are still thermal contributors.

Minimal positive electrode contribution

Graph showing normalized rate vs. temperature with various materials like LiCoO₂, Gen 2: LiNiₓCoₓMn₁₋ₓO₂, Gen 3: Liₓ(1/3)Niₓ/3(1/3)Coₓ/3(1/3)Mnₓ/3O₂, LiMn₂O₄, and LiFePO₄.

Courtesy: Saft

100 300 500 700
T °C

Normalized Rate (°C/Min)

0 100 200 300 400

Temperature (°C)
Developmental Areas of Interest

- High density components with superior performance: Large format, low impedance, high power batteries

- Higher voltage, safe cathodes to enable LTO and higher energy density variants of LFP

- Non-flammable, high power electrolytes

- High slew rate, high bandwidth, compact power conversion with minimal thermal management

- Allocation of available power and power system components to support multiple loads at the same time

- Rapid-charge energy storage capability

- High-rate operations across wider SOC
Conclusions

• Energy storage is an enabler for DEWs and for lower-consumption, high efficiency operations

• Even the best prime movers need augmentation of instant power capability of stored energy (e.g. batteries)

• Future platforms will be designed to accommodate substantial installed storage to compliment high power generation

• DoD Does not drive the market – Electronics and Advanced Transportation Batteries will

• Partnerships between DoD and DoE/DoT and industry groups can better foster markets and commonality that will ensure widespread adoption
QUESTIONS?