Development of the MFF Battery

Eugene Marquis
(Code G34
Phone 540-653-6020
e-mail: MarquisEE@nswc.navy.mil)

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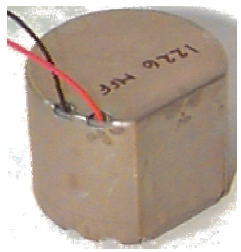
Program Background

- Objective: Develop a replacement battery for the MK 44 lead acid liquid reserve battery
- Development started in 1996 to replace the lead acid liquid reserve MK 44 battery
  - MOFA battery with extra cells
- This effort concluded in 1999 with little success but many lessons learned
  - Improvements to testing by switching loads & using voltage regulator & fixed resistor
  - Improvements to the design of the battery
  - Desire to improve electrolyte risetime



Program Overview

2 Prong Approach

- #1: Modify the Army's MOFA liquid reserve battery for use in the Navy's Multi-Function Fuze
  - Task began in 2001
  - Increase voltage from MOFA's 5.6V to 12.5V
  - Increase current draw from MOFA's 325mA to 450mA
  - Issues
    - Requires mechanical modification to fuze
    - Rise time issue

- #2: Modify Thales's liquid reserve battery
  - Task added in 2002
  - Same Fit & Form of MK 44 battery
  - Issue
    - 5 foot drop may fracture glass ampule

1st Approach: ATK

- 1st Electrolyte Study
- 2nd Electrolyte Study: High Rate Electrolyte Study
- Build 80 batteries with 5x2 configuration
- Performance test

1st Electrolyte Study

- Objective: Identify an electrolyte with a faster risetime than MOFA electrolyte
- NSWC-Carderock & ATK investigated several electrolytes
  - Electrolyte required to work with current MOFA cells
- Conclusion: No potential candidates identified

2nd Electrolyte Study

High Rate Electrolyte (HRE) Study

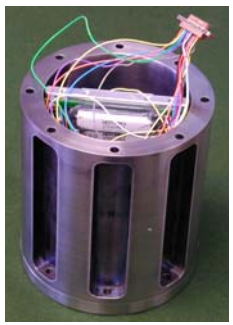
- Objective: Identify an electrolyte with a faster risetime than MOFA electrolyte
- Testing a different class of electrolytes than the 1st electrolyte study to improve risetime over MOFA
- Identified two electrolytes that could have better rise time
  - Based on the capacity
  - No ability to test risetime in the lab w/o building batteries
- Used MOFA batteries filled with the two HREs
  - Control – MOFA batteries with MOFA electrolyte
- Railgun test: Risetime
- Airgun test: Mission life / capacity
  - Improvements to airgun may activate batteries better & thus could test risetime

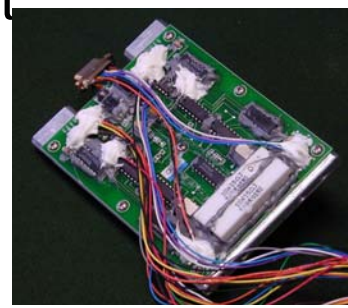
HRE Study: MFF Load Circuit

- Battery voltage is measured across the battery
- Battery current is measure by the voltage drop across a 0.5 Ω resistor
- A voltage regulator is used with a fixed resistor on the output side so that the current draw from the battery is constant after the minimum voltage even as the voltage increases
- Battery comes up under a light 60 mA load
- At 100ms, the heavy load is switched in
  - Designed to pull 450mA from the battery when the battery voltage is 7.5V or more
    - 7.5v on a 3 cell MOFA battery is equivalent to a 12.5v on a 5 cell MFF battery

HRE Study: MFF Load Circuit

- Similar MFF Load Circuit designs used in railgun and airgun testing
  - Airgun version
    - Unknown battery orientation is rectified using diode steering circuit
    - Voltage drop across diodes accounted for
  - Railgun version
    - Ruggedized to survive gunfiring environment
    - T_0 sensed by G-switch
    - Data recorded by On-Board-Recorder





1st Approach: ATK

HRE Study: Railgun

- Risetime Results

HRE	Total Test	Temp. (°F)	Met 7.5V @ 50ms	Met 7.5V before load	Met 7.5V after load	Met 7.5V @ 200ms	Met 7.5V @ 300ms	Met 7.5V @ 10sec
#2	5	20°F	0%	100%	0%	20%	20%	100%
#2	4	50°F	0%	25%	0%	25%	25%	100%
#2	4	70°F	50%	100%	0%	25%	100%	100%
#2	6	130°F	100%	100%	100%	100%	100%	100%
#7	5	20°F	0%	100%	20%	20%	40%	100%
#7	4	50°F	0%	0%	0%	0%	0%	100%
#7	4	70°F	0%	100%	0%	0%	0%	100%
#7	5	130°F	0%	20%	0%	20%	40%	100%
MOFA	2	20°F	50%	100%	0%	50%	50%	100%
MOFA	1	130°F	100%	100%	100%	100%	100%	100%

*The load of 450 mA was switched in at 100 msec

HRE Study: Airgun

1st Approach: ATK

Mission Life Results

HRE	Total Test	Temp. (°F)	Met 7.5V @ 50ms	Met 7.5V before load*	Met 7.5V after load	Met 7.5V @ 200ms	Met 7.5V @ 300ms	Met 7.5V @ 10sec	Met 7.5V @ 140sec
#2	3	20ºF	0%	100%	0%	0%	67%	100%	100%
#2	3	50ºF	100%	100%	0%	67%	100%	100%	100%
#2	3	70ºF	100%	100%	0%	67%	100%	100%	100%
#2	3	130ºF	100%	100%	100%	100%	100%	100%	100%
#7	3	20ºF	0%	67%	0%	0%	0%	100%	100%
#7	3	50ºF	0%	100%	0%	100%	100%	100%	100%
#7	3	70ºF	0%	100%	0%	67%	100%	100%	100%
#7	3	130ºF	67%	100%	67%	67%	67%	100%	67%
MOFA	5	20ºF	100%	100%	100%	100%	100%	100%	0%
MOFA	6	50ºF	100%	100%	83%	100%	100%	100%	0%
MOFA	7	70ºF	100%	100%	100%	100%	100%	100%	29%
MOFA	6	130ºF	100%	100%	100%	100%	100%	100%	33%

*The load of 450 mA was switched in at 100 msec

HRE Study: Combine Results

HRE	Total Tested	Temp.	Met 7.5V @ 50ms	Met 7.5V before load*	Met 7.5V after load*	Met 7.5V @ 200ms	Met 7.5V @ 300ms
#2	8	20 ºF	0%	100%	0%	13%	25%
#2	7	50 ºF	43%	86%	0%	43%	57%
#2	7	70 ºF	71%	100%	0%	43%	100%
#2	9	130 ºF	100%	100%	83%	100%	100%
#7	8	20 ºF	0%	100%	0%	13%	25%
#7	7	50 ºF	0%	42%	0%	43%	43%
#7	7	70 ºF	0%	100%	0%	29%	43%
#7	8	130 ºF	25%	50%	25%	38%	50%
MOFA	7	20 ºF	86%	100%	71%	86%	86%
MOFA	6	50 ºF	100%	100%	83%	100%	100%
MOFA	7	70 ºF	100%	100%	100%	100%	100%
MOFA	7	130 ºF	100%	100%	100%	100%	100%

Conclusion: Stay with MOFA electrolyte

2nd Approach: Thales

- Approach #2: modified European battery
  - Used in DM52A2 & DM84 fuzes
  - 2 Sources
    - Thales
      - Built 80 batteries (5x2 configuration)
      - Glass ampoule
        - Susceptible to breakage and thus battery activation
        - Should not be a serious safety issue
        - Affects long term reliability
    - Diehl/Eagle-Picher
      - Recently enter US market
      - Capable of 5x2 configuration
  - Build prototype designs for testing & for fuze integration

2nd Approach: Thales

- Thales became interested in modifying their design from a max of 9 cells to a max of 10 cells for a 5x2 battery capable of 450mA
  - Preliminary performance testing on 4x2 battery configuration was inconclusive due to test hardware malfunction
  - Preliminary safety testing on 4x2 battery configuration was conducted & identified typical issues with glass ampule which could cause noteworthy concern with Lithium battery in extremely rare case
  - Thales delivered 80 5x2 batteries
  - Batteries to be tested along side ATK 80 5x2 Mod-MOFA-2 batteries

Conclusion

- Risetime performance data for the MOFA battery can be obtained using ARL's upgraded airgun
  - Airgun produces enough G-force verses time to activate the MOFA battery
- Awaiting delivery of 80 Mod-MOFA-2 batteries so that side-by-side testing can be conducted on both ATK & Thales