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Mid Range Fuze Power
- Energy Harvesting/Batteries/or?

56th Fuze Conference
May 16th, 2012, Baltimore, MD
Harald Wich
Outline

- Recapitulation
- Energy Provisioning
- Munitions unique Energy Sources
- TE – Conversion
- Test Setup
- TEG Energy Source
Recapitulation

- Fuze Categories
  - PD  Det
  - SD  Det + Timer
  - ET  Det + programmable Timer
  - PX  Det + prog. Timer + TX/RX
  - CCF Det + prog. Timer + TX/RX + Control Power

- Operating Times
  - short $\leq 10 - 20$ sec  direct fire
  - medium $< 100$ sec  indirect fire Mortars
Recapitulation

- **Fuze Categories**
  - PD: $1 \text{ mJ} / 25 \text{ mJ}$
  - SD: $(1 \text{ mJ} / 25 \text{ mJ}) + 0.01 \times t \text{ mJ}$
  - ET: $(1 \text{ mJ} / 25 \text{ mJ}) + 1 \times t \text{ mJ}$
  - PX: $(1 \text{ mJ} / 25 \text{ mJ}) + 1 \times t_1 + 200 \times t_2 \text{ mJ}$
  - CCF: Det + prog. Timer + TX/RX + Control Power

- **Operating Times**
  - short: $\leq 10 – 20 \text{ sec}$
  - medium: $< 100 \text{ sec}$

- **Energy**

  Energy Requirement for Medium Calibre ranges from $1 \div 100 \text{ mJ}$

  ![Graph showing energy requirements](image.png)
How is the Fuze Energy provide

- A wide range of Energy levels
  - less than 10 mJ’s; well covered by a plethora of Setback Generators
  - above 1 J; well covered by Reserve Batteries and EM-Air Turbines

⇒ mid range – defined here as 10 mJ ÷ 1,000 mJ – is somewhat diverse

- Why is that?
  - Batteries and Turbines can certainly cover the Energy range required however, it is difficult to get them small enough
  - Setback Generators grow rapidly in size if higher Energy Output is required

Energy Density is the Keyword
Energy Density

- As a reminder from last year’s presentation:
  - Energy density for Setback Generators has not exceeded 5 µJ/mm^3 (neither EM- nor Piezo-Type) over the last 70 years!
- Whereas requirements of
  - 60 µJ/mm^3; 30 mJ total, (industrial customer)
  - 40 µJ/mm^3; 60 mJ total, (US SBIR A09-032 [Army])

do exist!

<table>
<thead>
<tr>
<th>example</th>
<th>requirement</th>
<th>10 mJ</th>
<th>100 mJ</th>
<th>1,000 mJ</th>
<th>10 J</th>
</tr>
</thead>
<tbody>
<tr>
<td>EM-, PZ- setback generator</td>
<td>2,000 mm^3</td>
<td>20,000 mm^3</td>
<td>200,000 mm^3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 x 12 TLC reserve battery</td>
<td>1 mm^3</td>
<td>10 mm^3</td>
<td>100 mm^3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

An Alternate System should/must cover 10 mJ ÷ 1,000 mJ
Energy Sources

- Where could the energy come from

Using energy sources all around us to power everyday electronic devices!
Where could the energy come from

- pressure
- temperature
- thermoelectric
- in-flight vibration
- angular acceleration
- setback force
- piezoelectric
- electromagnetic

- source requires storage device
- range of velocity
- air intake
- EM air turbine
- RAM-Air
- aerodynamic heat
- thermoelectric
- thermo photovoltaic
- rise time
- high speed only

From last years presentation
Energy Sources

- Where could the energy come from

Where could the energy come from

- pressure
- temperature

thermoelectric
- access

setback force

piezoelectric  electromagnetic

in-flight vibration

piezoelectric  electromagnetic

angular acceleration

electromagnetic

source requires storage device

- range of velocity
- air intake

EM air turbine

RAM-Air

aerodynamic heat

thermoelectric

thermo photovoltaic

- rise time
- high speed only

Our Research focused on Thermoelectric Conversion

low $T_{\text{max}}$, high $U_{\text{TEG}}$

high $T_{\text{max}}$, medium $U_{\text{TEG}}$

very high $T_{\text{max}}$, low $U_{\text{TEG}}$
Harvesting from a Temperature-(difference)

- As a conservative approach lets assume to generate 1,000 mJ electrical output requires 100 J at η = 1%, and 1,000 J at η = 0.1% thermal input.

- Two options to harvest thermal energy in a projectile:
  - **Projectile Base**: heat transfer during barrel transit, high temperature, very short duration.
  - **Projectile Nose**: heat transfer during free flight, low temperature, delayed response.
Harvesting from a Temperature-(difference)

- Is a projectile base able to harvest $10 \div 1,000$ J during barrel transit
  
  e.g. 40 mm IG HV interaction time $< 15$ msec $\Rightarrow 1 \div 100$ kW thermal input
  projectile total energy $\approx 10$ kJ kinetic energy
  
  Fast energy transfer from hot gases to heat sink as well as structural requirements prevents good thermal insulation

- Can a projectile nose harvest $10 \div 1,000$ J in flight
  
  e.g. 40 mm IG HV projectile velocity $v_0 \approx 240$ m/sec
  rather low $\Delta T \approx 16$ °C for max velocity
  
  Low $\Delta T$ requires high Seebeck coefficient or/and number of TE-Couples
  Temperature rise time delays availability of electric energy

Is this the End of our Story?
TE Energy Conversion

- Thermoelectric conversion – notoriously – suffers from very low efficiency
TE Energy Conversion

- Thermoelectric conversion – notoriously – suffers from very low efficiency

\[ P_{\text{el}} = \eta \times P_{\text{heat}} \]

TE Conversion requires very high Energy Heat Source
**TE Energy Conversion**

- Thermoelectric conversion – notoriously – suffers from very low efficiency

![Diagram of Thermoelectric Generation (TEG)](image)

- TE energy conversion requires heat source and sink capacities

- High power at start
- Long lifetime with high $R_{th}$ and good thermal insulation
Thermoelectric Test Setup

- Evaluation of the principle with internal heat source

**TEG with internal Heat source looks feasible**
TEG with internal Heat

- How to provide the internal heat energy
  - as an example Fe/KClO₄
    - to generate 100 mJ 1,000 mJ electrical output
    - requires 2.5 mm³ 25 mm³
    - 25 mm³ 250 mm³
    \[ \eta_{\text{tot}} = 1\% \]
    \[ \eta_{\text{tot}} = 0.1\% \]
  - heat powder!

- Compact heat source is feasible
  - Even 1,000 J heat capacity is less than ¼-inch cube
- Micro size TEG´s are available off-the-shelf
- Miniaturisation of activation system will be the future challenge

100 µJ/mm³ will already be reached with existing Activation
TEG Energy Source Perspective

- TEG-Power Sources with internal Heat are very feasible for mid range Energy Requirements $10 \div 1,000$ mJ
  - very robust design (no liquids, glass ampoules, etc.)
  - no spin required for activation
  - works under high spin environment
  - very long storage live
    - no corrosive electrolyte
    - hermetically sealed
  - no toxic materials
  - high peak power on start
  - energy density to be estimated $\geq 500 \, \mu$J/mm$^3$
    (100 x setback generators density)

TEG’s with internal Heat Source can cover mid range Power Requirements
Thank you for your Attention!

Any Questions, Comments, Objections, …
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Diehl & Eagle Picher in a Nutshell

About the company

- US/German Joint Venture; Shareholders are Eagle Picher Technology, Joplin MO and Diehl BGT Defence, Ueberlingen GE
- Located in Roethenbach Germany
- Thermal- and Fuze-Batteries and Battery Packs
- R&D and Production of the above Batteries and Energy Sources of all kind for Fuzes, Munitions and Missiles
- Annual Turn Over > 10 mEur
Small Liquid Reserve Battery

- For small and medium calibre applications

- 12 mm diameter
- 12 mm high
- single cell Lithium Battery
- 3.0 ÷ 3.6 V closed circuit voltage
- up to 50 mA load current
- setback/spin activation mechanism
  - > 7000 g activation
  - fast - < 5 ms - activation under spin environment
- lifetime > 50 s
- wide temperature range -46°C to +63°C
- very long shelf life – up to 20 years
- reliable
- low cost

Lithium Liquid Reserve Batteries provide superior Energy Density