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Design and Operation of the Compact 680kJ Pulse Forming Network (PFN) for Electromagnetic Launch

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1. Introduction

- **Pulse forming network (PFN) is very important for an electromagnetic launcher (EML).**

- **For strong operability of EML system, considerations were taken and work has been done to develop the earlier described PFN.**

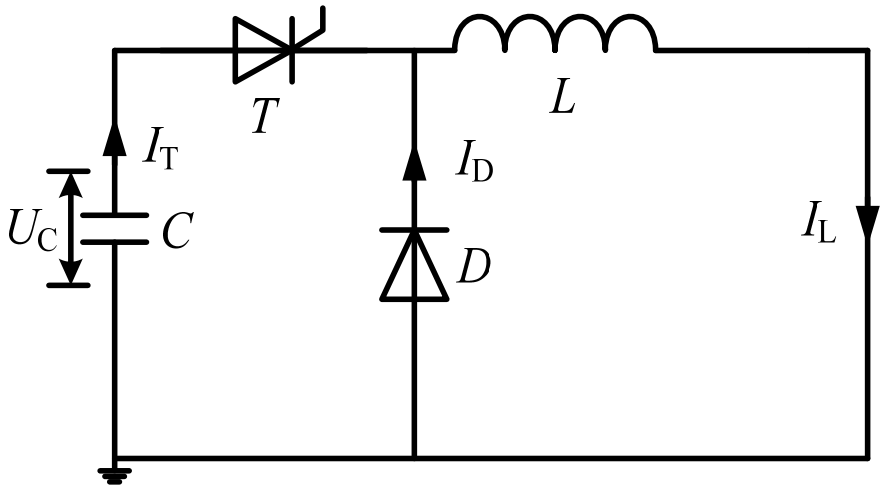
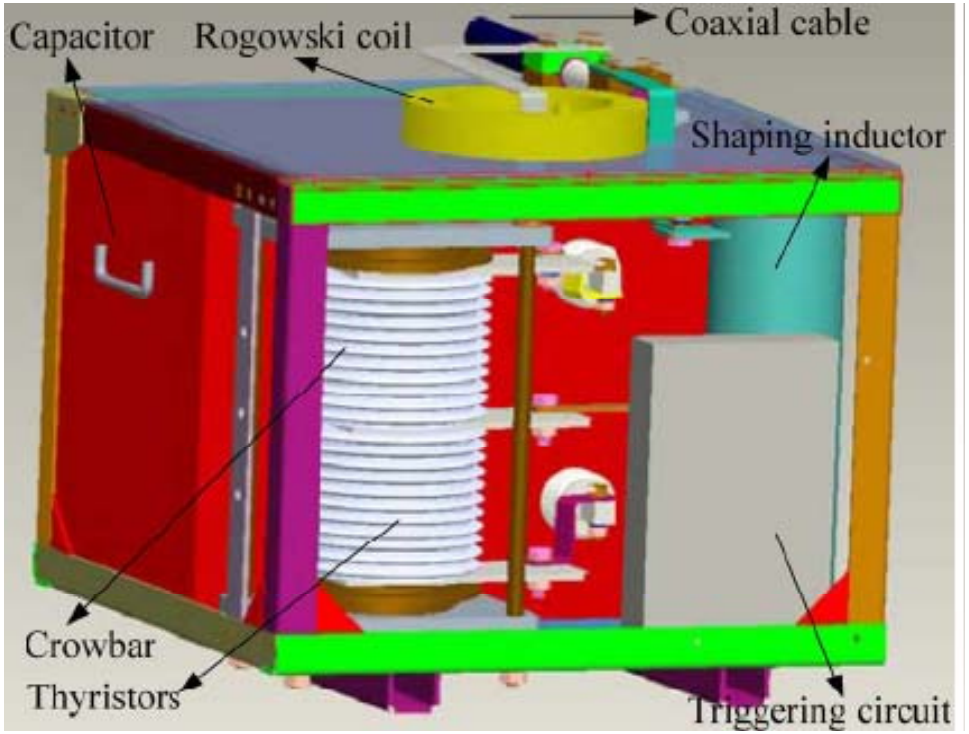


Fig 1. Electrical circuit of a PFU

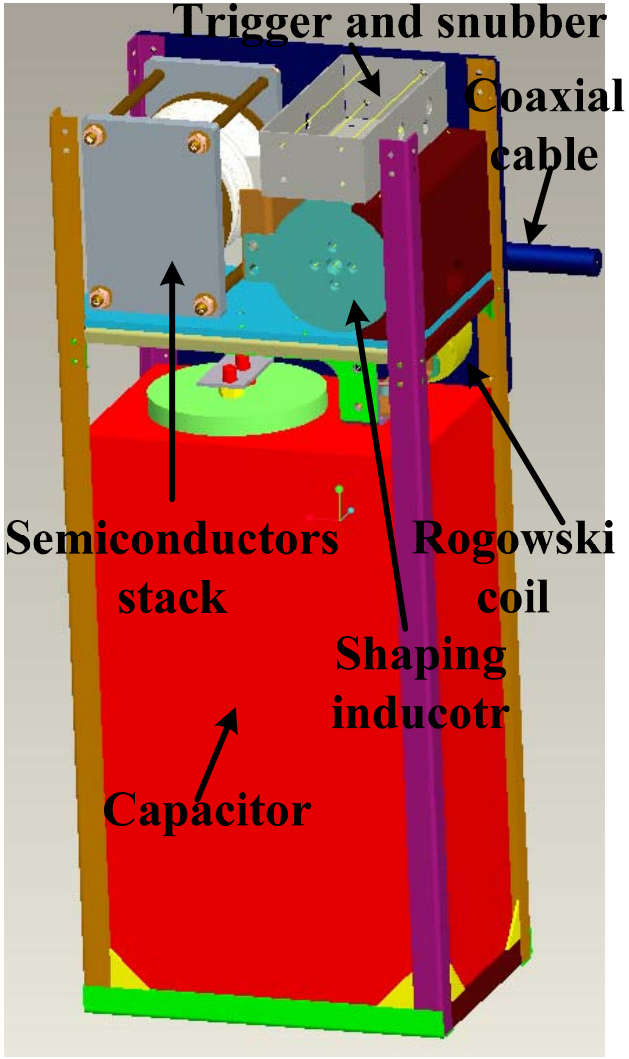
PFN consists of several pulse forming units (PFUs). Each PFU is composed of a main capacitor, a main switch, a crowbar and a pulse-shaping inductor.



- **PFU energy: 75 kJ**
- **Capacitor: 1000 μF/12.2 kV**
- **Main switch: thyristor**
- **Crowbar: diode**
- **Pulse-shaping inductor:15 μH/18 mΩ**
- **Peak current: 85 kA**
- **Peak time: 190 μs.**

Fig 2. Setup of a previous 75 kJ PFU

Y. Liu, F. Lin, L. Dai, and Zhang Qin, et al. Development of a Compact 450kJ Pulsed Power Supply System for Electromagnetic Launcher. *IEEE Trans. on Plas. Sci.*, 2010. (IEEE EARLY ACCESS)



- PFU energy: 85 kJ
- Capacitor: 2344 μF/8 kV
- Main switch: thyristor
- Crowbar: diode
- Pulse-shaping inductor:10 μH/2 mΩ
- Peak current: 130 kA
- Peak time: 240 μs.

Fig 3. Setup of a 85 kJ PFU

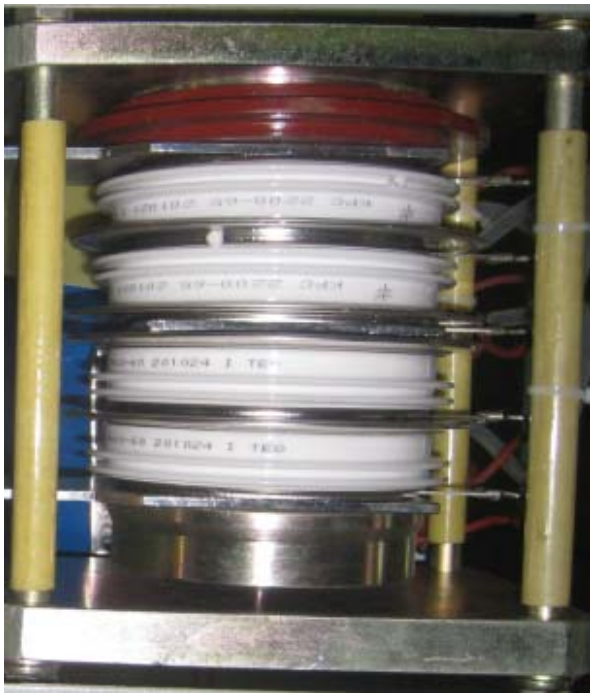
2. Components of PFN

A. Capacitors

- Energy density: 1.7 MJ/m^3
- Charge/discharge cycles: at least 1000 (at maximum energy density)
- Capacitance: 2344 μF
- Maximum operation voltage: 8.5 kV

Fig 4. Photo of main capacitor

B. Thyristor and crowbar diode



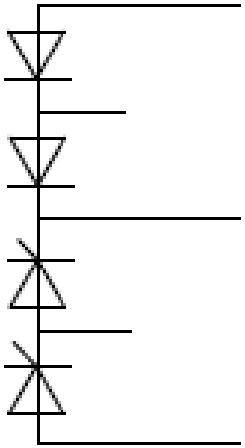


Fig 5. Compressed thyristors and diodes stack

Parameters of thyristor valve:

- **Diam of chips: 4 inch**
- **V_{DRM} =6.5 kV**
- **I_{max}>140kA (400 μs pulsewidth)**
- ***di/dt* >1 kA/μs**

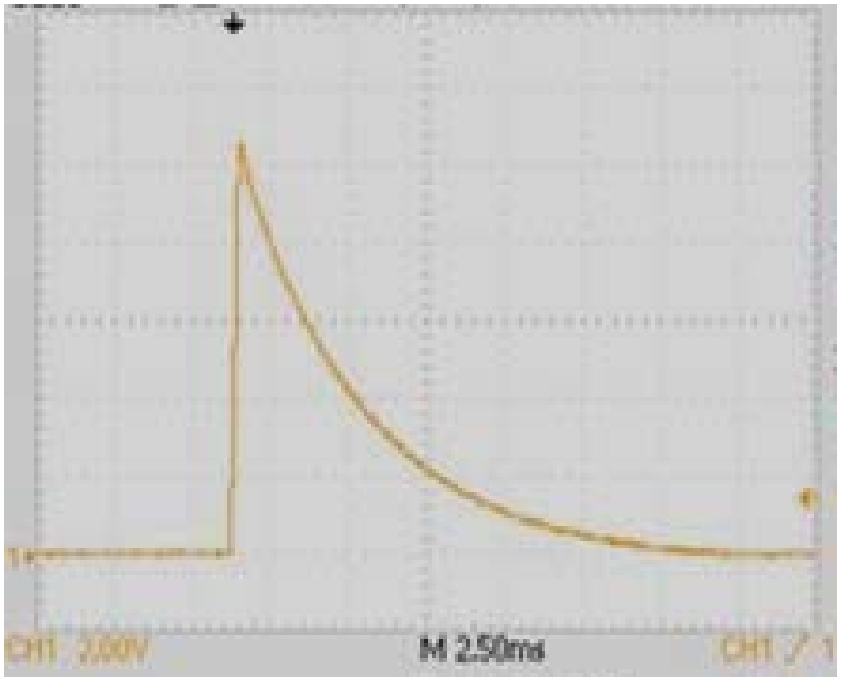
Parameters of diode valve:

- **Diam of chips: 4 inch**
- **V_{DRM} =5.2 kV**
- **I_{max}> 300 kA (400 μs pulsewidth)**
- **$\int I^2 dt > 22.16 \times 10^6\ A^2s$**

3. PFN Test

A. Initial test

Initial test have been done by discharging the PFUs into a short-circuit load.



- **Peak value：105 kA**
- **Peak time: 240 μs**

Fig 6. Current waveforms of a PFU fired at 7kV

B. Sequentially fired PFN

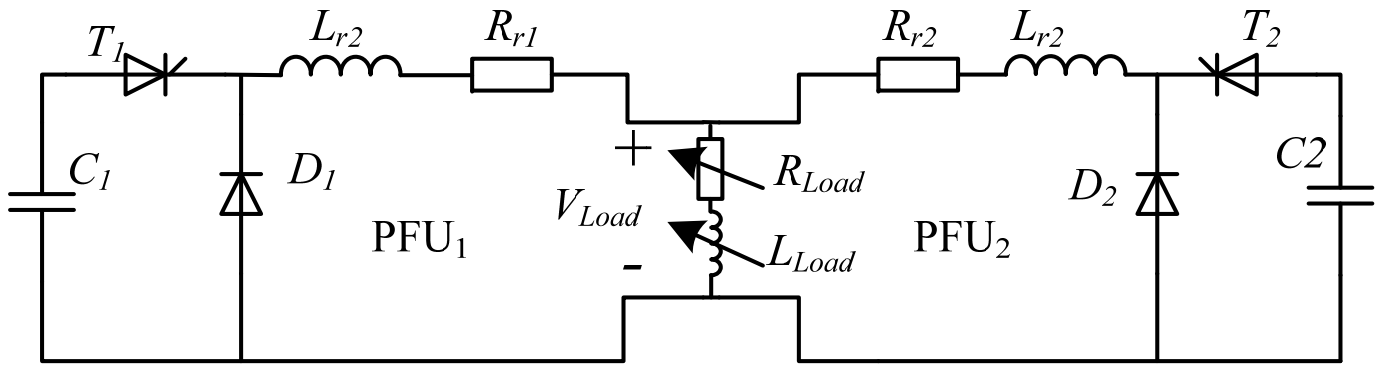


Fig 7. Diagrams of two PFUs

R_{load} and L_{load} are time variance and the polarity of V_{load} is the decisive factor for safety of semiconductors.

Voltage of the load

$$U = d\phi / dt + Ri = d(Li) / dt + Ri = L_{load} di / dt + i dL / dt + Ri$$
$$= L_{load} di / dt + i(dL / dx \times dx / dt) + R_{load} i$$
$$= -(1/\tau)\ L_{load} i + iLv + Ri \geq 0$$

where, $L_{load} = xL'$;
$R_{load} = xR' + R_{arm} + vL'$;
L' — Inductance gradient of the rails;
R' — Resistance gradient of the rails;
v — Projectile velocity;
x — Length of the rail current path;
R_{arm} — Resistance of the armature.

For a railgun as a load, the inductance L_{load} and the resistance R_{load} will be given by

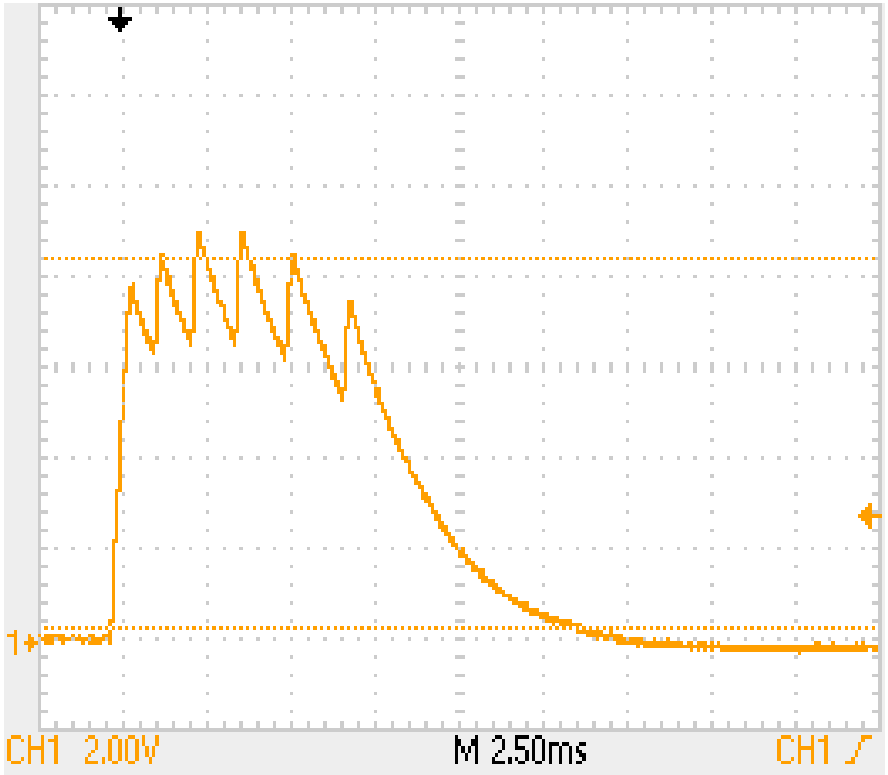
$$L_{load} = xL' \text{ and } R_{load} = xR' + R_{arm} + vL'$$

When the rail gun is the series augmented rail , the initial resistance R_0 and inductance L_0 of the rail should be considered.

Critical relationship

$$(xR' + R_{\text{arm}} + \text{v}L' + R_0)/(xL' + L_0) \geq R_{PFU} / L_{PFU}$$

Seven PFUs sequentially fired into a short-circuit load with the charge voltage of 2 kV.



➢**Peak value：>100 kA**

Fig 8. Seven PFUs sequentially fired at 2kV

4. Summary

- **The total energy density of the PFU is 0.84 MJ/m^3.**

- **The PFN can be fired sequentially and output flat current wave. It is reliable and is flexible for electromagnetic railgun.**

Thanks for your attention!

IPPT