Overview

Specific Electromagnetic Propulsion Topics

Technology for Pulse Inductive Thruster

Flight Weight Magnet Survey

Magnetic Flux Compression

Summary

Space Transportation Technology Workshop or Section Title:

Electromagnetic Propulsion
Technology goals and objectives

- Revisit PIT technology and design, build, and test a multi-repetition rate pulsed inductive thruster.
- Solid-State Switch Technology
  - High repetition rate and extreme long lifetime
  - High peak currents and high/rapid initial current rise time
- Pulse Driver Network and Architecture
  - Recovery of reflected energy
  - Pulse shape control for optimum pulse waveform

Background

- Research history since 70's at TRW
- Characterized by μ-second, MW-power pulsed operation providing high thrust efficiency over a wide range of specific impulse.
- Single-shot spark gap operation
  - Severe lifetime limitations
  - Multi-rep rate operation severely limited
  - Require gaseous working medium to enable high
  - Require extreme simultaneous discharge trigger operation

Space Transportation Technology Workshop or Section Title:

Electromagnetic Propulsion (PIT)
Current status

- **PIT Performance Characteristics**
  - Spec. Impulse: 2,000-8,000 s
  - Efficiency: 20-50%
  - Single shot operation using spark gaps
    - Initial Rise Time in one switch: $\frac{dl}{dt}=30kA/\mu s$
    - Peak Current: 15kA

- **Solid-State Switch Technology**
  - SCR: 5 kV, 4.6 kA, $\frac{dl}{dt}=20$ kA/μs
  - IGBT: 15 kV, 3kA, 10's of kHz

Major accomplishments

- Designed two test circuits to conduct testing of key parameters
- Procured test equipment and circuit components
- Identified manufacturers to supply high-power solid-state switch technology

Near term plans

- Test and evaluate candidate switch components

*Space Transportation Technology Workshop or Section Title: Electromagnetic Propulsion (PIT)*
FLIGHT WEIGHT MAGNETICS

MAJOR RESEARCH GOALS:
♦ Determine/develop light weight high performance magnetic materials. for potential application Advanced Space Flight Systems as these systems develop.

MAJOR ACCOMPLISHMENTS:
♦ Literature searches resulted in selection of Ultra Pure Aluminum to fabricate an electromagnet to generate a pulsed magnetic field in a cryogenic temperature environment. This selection was based on density, temperature-dependant and residual resistivity, as well as magneto-resistance characteristics.
♦ Acquired magnetic pressure equations (stress analysis).
♦ Located experienced source for electromagnet fabrication and testing

STATUS:
♦ A grant is currently in place with Louisiana State University (LSU) to construct a 99.999% Purity Aluminum solenoid. Will be delivered to MSFC after fabrication and testing is completed.

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FLIGHT WEIGHT MAGNETICS

MILESTONES:

November 2000
♦ Solenoid to be completed by LSU.
♦ Testing at the National High Magnetic Field Laboratory (NHMFL) in Tallahassee, FL. which includes:
  • Magneto-resistance recorded while exposed to externally applied steady state magnetic fields up to 20 Tesla and temperatures ranging from 4 to 300 Kelvin.

December 2000
♦ Testing at the NHMFL in Los Alamos, NM. which includes:
♦ Pulsed excitation to field maximum of 2 Tesla.
♦ Solenoid and cryogenic system temperature recorded during excitation.
♦ Measurements of the total solenoid resistance, inductance, and stress/stain before, during, after each excitation.

January 2001
♦ Solenoid and all data delivered to MSFC.

Space Transportation Technology Workshop or Section Title:
**Electromagnetic Propulsion – Magnetic Flux Compression Reactors**

**Goals**

Enable rapid/robust/reliable omni-planetary space transportation within realistic development and operational costs constraints

**Objectives**

10x improvement propulsion capability  
- high thrust-to-weight ratio  
- high specific impulse  
- high Δv maneuvering

Abundant spacecraft electrical power  
- deep space capability (non-solar)  
- high capacity (multi-MW)  
- high specific power (> 10 kW/kg)

**Technical Challenges**

Demonstrate the feasibility of pulsed magnetic flux compression reactor concepts using detonation plasma

Research and develop lightweight pulsed magnet technologies based on ultra conductors and superconductors

Fundamental plasmadynamics research  
- electrical conductivity / R_m  
- interactions with magnetic field  
- plasma instabilities  
- magnetic flux diffusion  
- plasma turnaround

Fundamental magnetics research  
- high purity aluminum windings  
- type I / type II SC windings  
- HTSC flux compression surfaces  
- lightweight structure issues  
- pulsed operation issues

**Approach**

Develop and test a moderate scale (1/2-m) prototype flux compression reactor using non-nuclear plasma detonation source
Rationale

Plasma micro-detonation flux compression reactors ...

- amenable to propulsion & electrical power reactor concepts
  - high jet power / multi-megajoule energy bursts
  - inductive energy storage / pulse power for ignition driver
  - production of spacecraft bus power
- compatible with advanced target concepts
  - inertial confinement fusion (ICF)
  - magnetized target fusion (MTF)
  - high energy density chemical detonations
- low-weight / compact / low-cost

... capable of satisfying omni-planetary exploration goals
Magnetic Flux Compression Reactor Principles

**Energy Conversion Processes**

chemical/nuclear → kinetic → electrical → kinetic

**Principle of Operation**

- detonation charge transformed into kinetic energy of moving conductor
- magnetic seed field is trapped and compressed by moving conductor
- kinetic energy is temporarily stored in rapidly compressed magnetic field
- electrical power can be extracted inductively through loaded circuit
- compressed field energy reverses conductor motion and returns kinetic energy

**Global Energy Conservation**

> 80%

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conversion efficiency
Major Research Tasks

- Modeling of reactor performance
  - first order performance analyses
- MHD code development
- finite element model of coupled circuits
- Investigation of pulsed magnetic fields on HTSC materials
- laboratory measurements of magnetic diffusion properties
- validation of magnetic diffusion model
- Basic plasma physics experiments
  - fundamental flux compression experiment
  - plasma jet collisional processes
  - validation of MHD codes
- Rayleigh-Taylor instability (revisited)
- Lightweight pulsed magnet technology
  - high purity aluminum winding magnet
  - Space transportation technology
  - superconductor winding magnet
Key Summary Points

- magnetic flux compression suitable for spacecraft propulsion & power
  - enables omniplanetary exploration
  - multimegawatt energy bursts
  - terawatt power bursts
  - pulse power for low impedance dense plasma devices
  - direct thrust production

- innovative design strategy
  - detonation plasma armature
  - type-II superconductor stator
  - intermittent firing capability

- constrains weight and size of overall system
- inductive storage pulse power source
- near-term (≈18 month) scientific feasibility program
- concept based on feasible extrapolations of current technology