Overview

Specific Electromagnetic Propulsion Topics

Technology for Pulse Inductive Thruster

Flight Weight Magnet Survey

Magnetic Flux Compression

Summary
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: $\frac{dl}{dt}=30\text{kA/\mu}$
      - Peak Current: 15kA
  - Solid-State Switch Technology
    - SCR: 5 kV, 4.6 kA, $\frac{dl}{dt}=20 \text{kA/\mu s}$
    - 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.
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.
Electromagnetic Propulsion – Magnetic Flux Compression Reactors

Goals ...

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

Objectives ...

10× 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 plasmdynamics 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%

Space Transportation Technology Workshop or Section Title: 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
  - inductive measurement of plasma jet electrical conductivity
  - plasma jet collisional processes
  - validation of MHD codes
  - Rayleigh-Taylor instability (revisited)

- Flightweight pulsed magnet technology
  - high purity aluminum winding magnet
  - 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