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Magnetic Flux Compression Concept for Aerospace Propulsion and Power

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The objective of this research is to investigate system level performance and design issues associated with magnetic flux compression devices for aerospace power generation and propulsion. The proposed concept, illustrated in Fig. 1, incorporates the principles of magnetic flux compression for direct conversion of nuclear/chemical detonation energy into electrical power. Specifically, a magnetic field is compressed between an expanding detonation driven diamagnetic plasma and a stator structure formed from a high temperature superconductor (HTSC). The expanding plasma cloud is entirely confined by the compressed magnetic field at the expense of internal kinetic energy. Electrical power is inductively extracted, and the detonation products are collimated and expelled through a magnetic nozzle. The long-term development of this highly integrated generator/propulsion system opens up revolutionary NASA Mission scenarios for future interplanetary and interstellar spacecraft. The unique features of this concept with respect to future space travel opportunities are as follows:

- ability to implement high energy density chemical detonations or ICF microfusion bursts as the impulsive diamagnetic plasma source;
- high power density system characteristics constrain the size, weight, and cost of the vehicle architecture;
- provides inductive storage pulse power with a very short pulse rise time;
- multimegajoule energy bursts / terawatt power bursts;
- compact pulse power driver for low-impedance dense plasma devices;
- utilization of low cost HTSC material and casting technology to increase magnetic flux conservation and inductive energy storage;
- improvement in chemical/nuclear-to-electric energy conversion efficiency and the ability to generate significant levels of thrust with very high specific impulse;
- potential for developing a small, lightweight, low cost, self-excited integrated propulsion and power system suitable for space stations, planetary bases, and interplanetary and interstellar space travel;
- potential for attaining specific impulses approaching 10^6 seconds, which would enable missions to the outer planets within ten years and missions at interstellar distances within fifty years.

The analyses conducted in support of this program have served to illustrate both the propulsion and power potential of this concept. For example, 5 to 10 gigawatts of power are achievable with fuel consumption rates on the order of 1 gram per second. Specific impulses of 10^6 seconds are achievable with comparable fuel burnup fractions (10-15%) as for the power generation rates cited. The analyses also served to identify the key technical issues associated with making this concept a reality. The use of plasma armatures does introduce substantial technical risks that must be addressed and overcome through research and development. The major uncertainties with the plasma armature approach are summarized as follows:

- ✓ achieving sufficiently high electrical conductivity in the detonation plasma;
- ✓ electron Joule heating effects;
- ✓ field aligned ion flow due to the ambipolar potential
- ✓ assurance of armature rebound;
- ✓ suppression of Rayleigh-Taylor instabilities.

The HTSC stators have associated with them, major uncertainties that may be categorized as follows:

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- ✓ breakdown of HTSC under strong applied pulse fields;
- ✓ hysteresis cycling of magnetization;
- ✓ joule/neutron heating of the material;
- ✓ structural integrity under cyclic loading;
- ✓ bulk-processed vs. wire fabrication.

To gain some perspective on this concept, analyses were carried out on a radially configured flux compression device using a high explosive driver as sketched in Fig. 2. Some typical analytical results for the flux compression coefficient (ratio of trapped flux to initial flux) are shown in Fig. 3. This analysis is based on a skin layer methodology first proposed by A. Sakharov for magnetoimplosive generators. The exploding plasma armature from a centrally located high explosive charge compresses the initial seed field against a cylindrical stator. The ability to successfully trap the flux clearly depends on the level of electrical conductivity that can be maintained in the stator material. Fig. 4 provides estimates for the plasma turnaround radius as a function of magnetic Reynolds number and initial seed field strength.

Some experimentation was accomplished to address the feasibility of the HTSC stator for flux compression applications. In this experiment, a cylindrical shell of stator material is surrounded by a pulsed solenoid, and the time for magnetic field penetration is measured using a Hall probe, as illustrated in Fig. 5. The two alternative HTSC materials considered were BSCCO and YBCO. The experiments proved that a BSCCO superconductor provides adequate resistivity to an applied magnetic field. That is, magnetic diffusion in a BSCCO superconductor is greatly reduced compared to that of regular metals, such as aluminum. This is evidenced by the field penetration characteristics shown in Fig. 6. Low magnetic diffusivity is a key element in proving that type-II high temperature superconductors can be used as stators in a pulsed power generation process. At this point in time no conclusions have been made with respect to the possible utilization of YBCO.

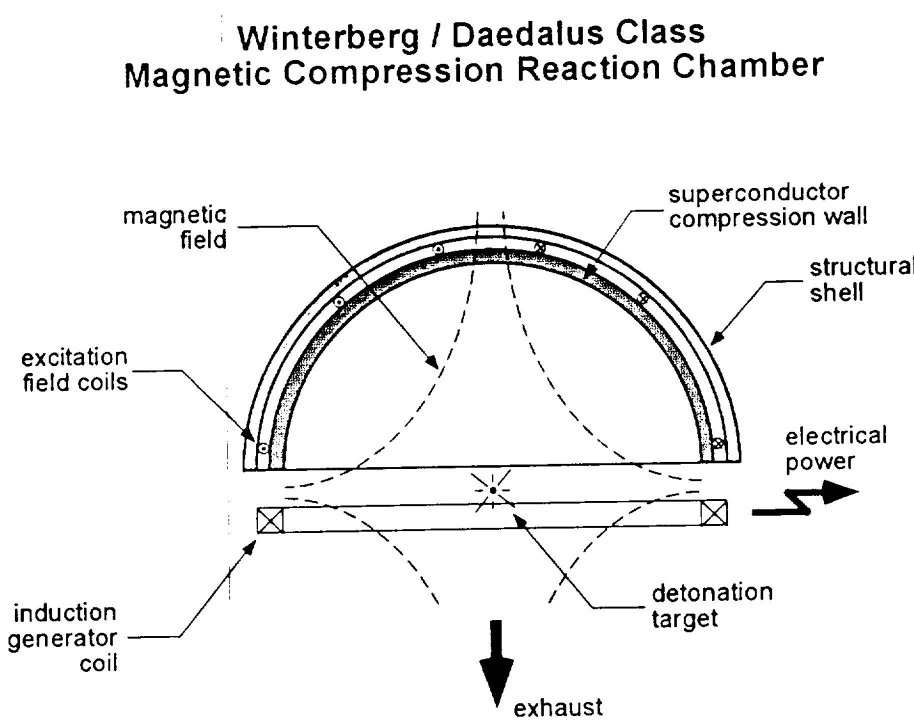

Figure 1: Winterberg/Daedalus class magnetic compression reaction chamber for integrated space propulsion and power applications.

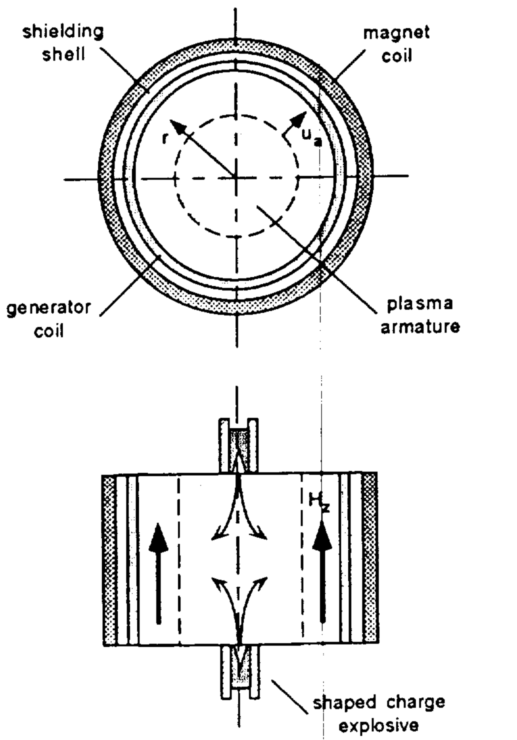

Figure 2: Mark I configuration for a radial mode explosively driven demonstration device.

Table I: High Explosive Characteristics

Density (ρ_D)	1700 kg/m^3
Specific Energy (w_D)	5×10^6 J/kg
Velocity (u_D)	1×10^4 m/s

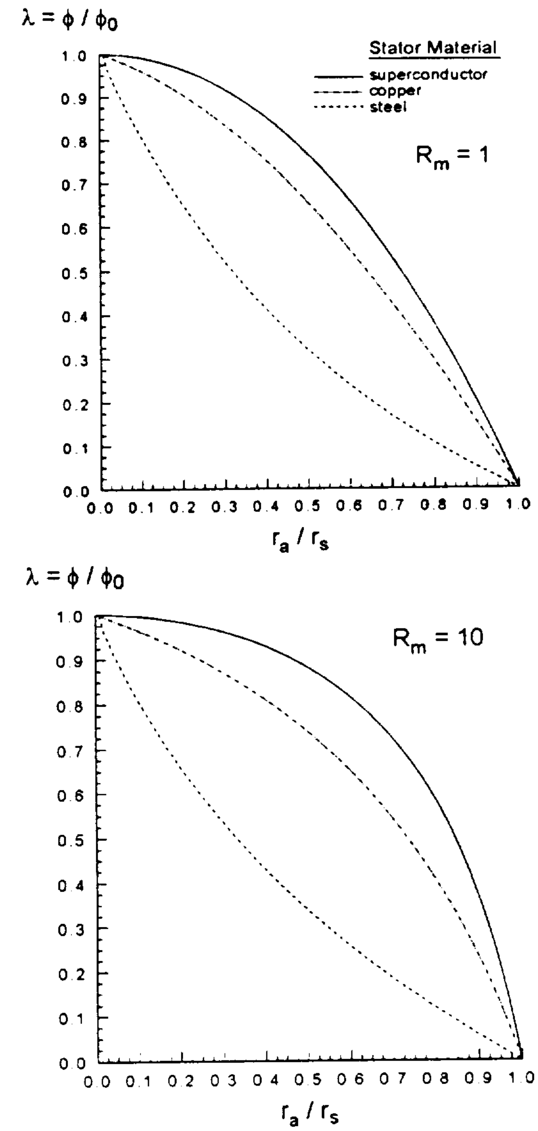

Figure 3: Computed flux coefficient for high explosive driven radial mode configuration.

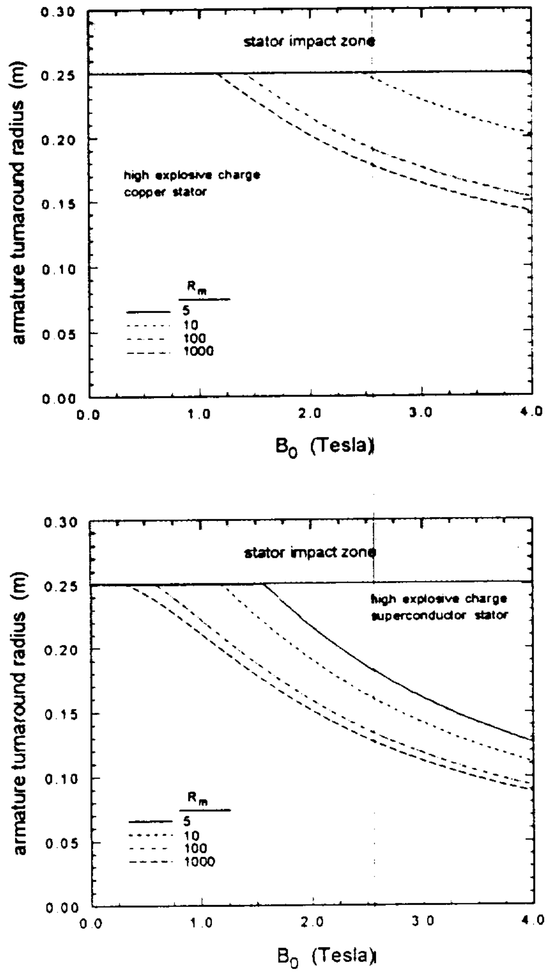

Figure 4: Computed armature rebound conditions for high explosive driven radial mode configuration.

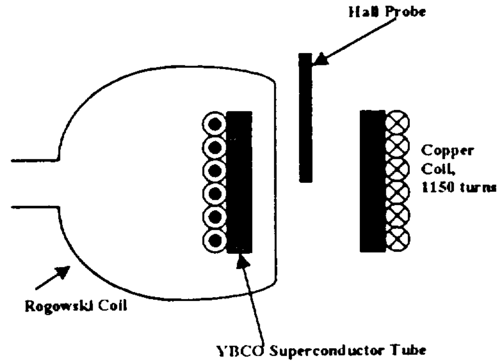

Figure 5: Experimental configuration for magnetic diffusion experiments.

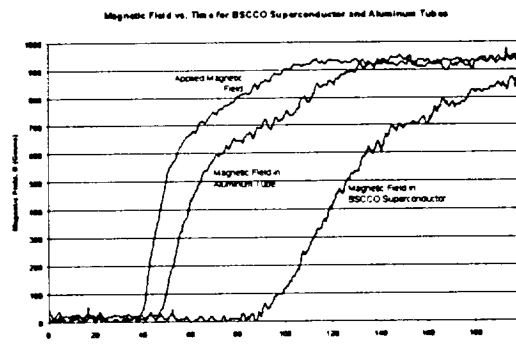

Figure 6: Measured magnetic diffusion characteristics for BSSCO and aluminum stator materials.