Antimatter-Initiated Microfusion: Direct Energy Conversion for Propulsion Applications

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Abstract. An analysis has been performed on major components of a direct energy conversion system DIPEC (Direct Propellant Ionization Energy Conversion) for AIMStar (Antimatter-Initiated Microfusion Starship) propulsion applications to deep space. Results for distributed energies, efficiencies, thrust and Isp are presented.

SUMMARY

An analysis has been performed on major components of a direct energy conversion system for AIMStar. These components include the fusion reactor, the expander, the propellant ionization chamber, the thruster and the direct collector.

The fusion reactor simulations were performed using the fuels DT and DHe^3. It was found that large magnetic fields (300/400 T) are required to provide zero order stable confinement. Using these fields, stable confinement and expulsion of the charged fusion products could be achieved, enabling direct energy conversion. The beam is 10 cm in radius, with the majority of particles inside 5 cm with a nearly uniform energy spectrum.

The expander was examined to determine geometry, field strengths, and efficiency. The magnetic fields can be successfully reduced from 400 T to 50 T, over an approximate 3-4 m distance with entrance and exit areas of 0.0314 m^2 and 0.188 m^2 with 83.3% efficiency.

The propellant ionization chamber provides an effective mechanism for ionization and transport of the propellant. 2 $\times 10^{18}$ Argon ions, per pulse, can be transported to an electrostatic thruster with an approximate 94% efficiency. The proposed design also ensures that the charged fusion products detach from the magnetic field lines and enter the direct collector.

The direct collector provides an efficient means of energy conversion of the high-energy alpha particles and protons. The major issue with the direct collector is voltage capacity. The thruster used in the system is an electrostatic thruster. This thruster type was chosen due to its fundamental understanding and ease of incorporation into the system. The requirements for an AIMStar type mission require propellant thrust of 1.966 N with a specific impulse of 59,300 seconds. Thruster simulations show that these requirements can be met using electrostatic fields of 75 kV over 1mm grid spacing. The whole propulsion pulse takes approximately 1.2×10^{-6} sec, excluding the 0.6 ms (DT) and 20 ms (DHe^3) required for a full fusion burn. This is the time it takes for the ionized propellant to move to the grid acceleration region. All other systems have operating times of nanosecond

Table 1 shows an accounting of energy in the system. 48.6 kJ of energy is available to power spacecraft subsystems and instruments using DT. This is within acceptable limits provided by previous studies suggesting that approximately 448 Watts is required to power the spacecraft instruments, etc.. However, with DHe^3 not enough

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power is available to mount the mission. It should be noted that this energy balance does not include the energy required to raise and lower the electric and magnetic fields in the system. The electric field generation in the reactor and direct collector is examined as inefficiency within the system and subtracted from the total energy available. The magnetic fields, especially inside the reactor, are extremely high and correspond to a large magnetic energy density. This necessitates the use of super conducting magnets to keep power requirements in check.

TABLE 1. Table of Energy Terms for AIMStar Power System.

Energy Term	DHe^3	DT
Energy Released from Reaction	+15 kJ	+ 80 kJ
Energy Lost to Brem. In Reactor	-4.9 kJ	-4.9 kJ
Energy Lost to Sync. Rad. In Reactor	-62.2 J	-62.2 J
Energy Lost Due to Particle Collisions with Reactor Walls	-0.15 kJ	-0.8 kJ
Energy Lost in Expander	-1.6 kJ	-12.4 kJ
Energy Collected in Collector and Available for Propulsion	8 kJ	+60.0 kJ
Energy Lost to Brem. In DIPEC	~ 0	~ 0
Energy Lost to Sync. Rad. In DIPEC	~ 0	~ 0
Energy Used in Ionizing Propellant	16 J	16 J
Energy Required To Accelerate Propellant to 60,000 s to reach 10,000 AU in 50 yrs.	-8.8 kJ	-8.8 kJ
Misc. Energy Losses (2 % of total available)	24 J	2.6 kJ
Energy Remaining for Spacecraft Power	***-816 J***	***48.6 kJ***

The estimated efficiencies of each component for each fuel are given in Table 2. The analysis illustrates the fact that if the conversion from fusion energy to propulsive thrust were 100% efficient, 730 kW would be required to accelerate an 1800 kg spacecraft to sufficient velocity to mount a 10,000 AU, 50 year mission. However, a full system analysis reveals only about 40% efficiency. Hence, of the original 750 kW (DHe^3) and 133 MW (DT), only 315 kW and 53.2 MW are available. In the case of DT, this is more than sufficient to power a spacecraft to 10,000 AU in 50 years. It is shown that a more modest mission of traveling to 3,500 AU over 50 years is possible.

TABLE 2. Individual Component Efficiencies.

Component	Efficiency	
	DT	DHe^3
Reactor	93 %	67 %
Expander	83 %	83 %
Thruster Ionization Chamber	94 %	94 %
Direct Collector	95 %	95 %
Neutron Collector	~35 %	n/a
Thruster (grids)	88%	88%
Generator/Storage	95 %	95 %
Overall	***40 %***	***42 %***