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Antiproton Driven Propulsion Systems – Fission or Fusion

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With the potential availability of sufficient amounts of antiprotons at reasonable costs in the next decade or so, it is reasonable to examine some currently envisaged propulsion systems that may utilize these particles, and ask what performance capability do they provide concerning certain missions that are contemplated in the same time frame. We focus in this paper on two systems: a gasdynamic mirror (GDM) propulsion system that uses U^{238} as a propellant for which the energy is provided by the "at rest" annihilation of antiprotons in U^{238} nuclei, and a magnetically insulated inertial confinement fusion (MICF) system where antiprotons are used to initiate fusion reactions in pellets containing fusion fuel. We employ these propulsion devices in two missions where in the interest of conserving the amount of antiprotons used we consider scenarios where thrusting is allowed for a certain period, followed by coasting, then followed by another thrusting period until reaching destination and a return trip following the same approach. One trip is to Mars, and the other to Jupiter in order to simulate a potential JIMO mission. We find that in the fission-based system a round trip to Mars will take 127 days with 2.2 days of thrusting if a gram of antiprotons is used, and a round trip to Jupiter will take 1012 days under the same conditions. The Mars and Jupiter missions can be achieved in 110 days and 780 days respectively with the use of the fusion MICF system for the same amount of antiprotons but requiring about 30 days of thrusting.

I. Introduction

With much interest in Mars and JIMO missions in recent months, considerable effort has gone into assessing propulsion systems that lend themselves to these missions. Fission and fusion driven systems appear to have the performance capability, but in both cases it appears that large masses may be a major obstacle to their utilization. Nuclear thermal propulsion may produce large thrusts but at very modest specific impulses, while fusion systems can produce specific impulses in the 100,000 seconds range but generally at modest thrust due to the small atomic mass of the propellant. In both instances, large masses are inherent since nuclear reactions and power conversion components are sizable, and in the case of steady state magnetic fusion devices, the need for injectors provides yet another sizable component. Many of these issues can perhaps be dealt with if antimatter is used to initiate the reactions that generate the energy which ultimately is used to heat the propellant to desirable temperatures. In this paper we examine two such systems in which the source of energy is the proton (p) antiproton ($\bar{p}$) annihilation reactions. In the first system, antiprotons are used to initiate fission reactions in a U^{238} target with the fission fragments and the annihilation products serving as the agents of energy transfer to the propellant which is subsequently ejected through a magnetic nozzle to produce thrust. In the second approach, antiprotons are made to annihilate inside a fusion fuel-containing target to effectively generate a hot plasma that undergoes fusion reactions for the life time of the pellet. At the end of the fusion burn, the hot plasma is also exhausted by means of a magnetic nozzle to produce thrust. In what follows a brief description of each system is provided.

II. Antiproton Powered Fission Propulsion System

This device, illustrated in Fig. 1, consists of an antiproton trap that is connected to a gasdynamic mirror (GDM) magnetic confinement device which will contain the U^{238} plasma while being heated by the fission fragments and the annihilation products produced when the beam of antiprotons strike the U^{238} foil. The principle of operation of this propulsion system is to inject radially, at an appropriate axial position, a U^{238} target either in a solid strip form or

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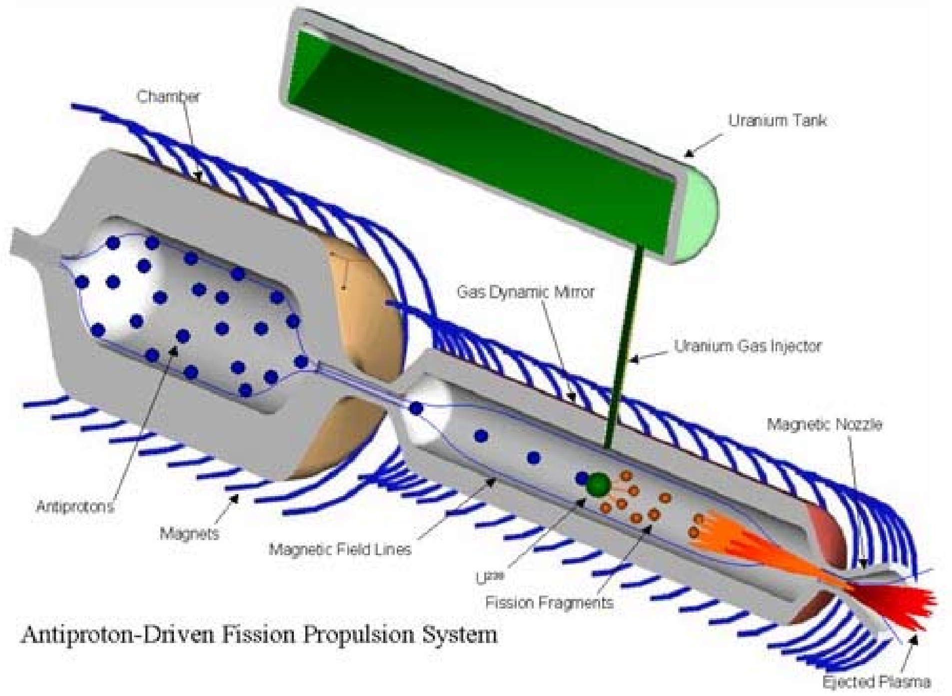

Figure 1. Schematics of the fission propulsion system based on the GDM concept.

as an atomic beam and then strike it with an axially injected pulsed antiproton beam to induce fission. The nearly isotropically emitted fission fragments will slow down on the electrons of the U^{238} gas which is inserted into the GDM just prior to the injection of the antiproton beam to provide the background plasma (propellant). It also serves as the medium for the transportation of the antiprotons from the point of injection into the target.

In a low temperature plasma of 6.5 eV (corresponding to the ionization energy of uranium), an energetic antiproton can slow down on the electrons or undergo annihilation reactions with the ions of the medium. Mathematical analysis[1] shows that in a plasma with density $n = 10^{16}$ cm^{-3} and temperature $T_e = 6.5$ eV, an antiproton injected at an energy of 20 keV will reach an energy of almost zero at a distance of 28 cm. This determines the position of the U^{238} strip, where upon being struck by the antiproton beam undergoes "at rest"[2] annihilation and the release of fission fragments and annihilation products. These charged particles heat the electrons of the propellant, which subsequently transfer energy to the ions in a characteristic time known as the "thermalization time". This time defines the confinement time of the GDM, which in turn allows for the calculation of the relevant parameters of the device. It is shown that such a system can produce about 48 kiloNewtons of thrust at a specific impulse (Isp) of about 3000 seconds and can make a round trip Mars mission in about 127 days with 2.2 days of thrusting, requiring one gram of antiprotons to achieve it. A round trip Jupiter mission under the same conditions will take 1012 days.

III. Antiproton Driven Magnetically Insulated Inertial Confinement Fusion (MICF) Propulsion System

This system[3] combines the favorable aspects of both magnetic and inertial fusions in that physical containment of the hot plasma is provided by a metallic shell while its thermal energy is insulated from the material wall by a strong, self-generated magnetic field. Unlike the conventional implosion-type inertial fusion schemes, energy production in this approach does not require compression of the fuel to many times solid-state densities and simultaneous delivery of energy to the core to initiate the burn. Instead, the fusion plasma is created through wall ablation by an incident particle beam that enters the target through a hole.

The propulsive capability of MICF depends critically on its ability to sustain an ignited fusion plasma and the generation of large amounts of energy as typified by large Q-values, where "Q" is the ratio of fusion energy to input energy. Studies[4] have shown that Q-values of several hundred and even thousands are achievable due to the long burn time provided for by the presence of the strong magnetic field. In this study, we examine the propulsive capability of an antiproton-driven MICF propulsion system. We find that an MICF system, utilizing 3 gram pellets of 0.25 cm radius, can generate a plasma with density of 5×10^{21} cm^{-3} at a temperature of 10 keV when struck by a beam of antiprotons. In fact we find that at a rep rate of 100 s^{-1}, the system is capable of producing about 17 kiloNewtons of thrust at an Isp of 4500 seconds. With a dry mass of 222 metric tons, we find that this propulsion device can carry out a Mars round trip mission in about 110 days with approximately 31 days of thrusting and requiring one gram of antiprotons. A Jupiter mission can be carried out in 780 days for the same thrusting time and antiproton amount.

References

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