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INERTIAL-ELECTROSTATIC CONFINEMENT (IEC) FUSION FOR
SPACE PROPULSION

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Inertial-Electrostatic Confinement (IEC) Fusion for Space Propulsion

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ABSTRACT

An Inertial-Electrostatic Confinement (IEC) device was assembled at the Marshall Space Flight Center (MSFC) Propulsion Research Center (PRC) to study the possibility of using IEC technology for deep space propulsion and power. Inertial-Electrostatic Confinement is capable of containing a nuclear fusion plasma in a series of virtual potential wells. These wells would substantially increase plasma confinement, possibly leading towards a high-gain, breakthrough fusion device. A one-foot in diameter IEC vessel was borrowed from the Fusion Studies Laboratory at the University of Illinois@Urbana-Champaign for the summer. This device was used in initial parameterization studies in order to design a larger, actively cooled device for permanent use at the PRC.

INTRODUCTION

A propulsion and power source of increased efficiency is required in order to make regions of space beyond low earth orbit readily accessible for exploration and commercialization. To achieve this goal the Propulsion Research Center (PRC) at Marshall Space Flight Center (MSFC) is investigating, among other concepts, nuclear fusion power. And one of these approaches to controlled fusion is Inertial-Electrostatic Confinement (IEC). This paper will describe IEC, offer a brief historical account of the research that has gone into the concept, describe the efforts in IEC at Marshall to date, and discuss some of the possible applications of the technology to space power and propulsion.

The goal of this summer effort in IEC was to 1) assemble a working IEC device on site at MSFC; 2) familiarize PRC staff in the operation of an IEC device; 3) design the next generation IEC experiment for the PRC lab; and 4) conduct some initial experiments in the use of IEC for deep space thrust. The first two objectives were easily met; the fourth objective, however, was not successfully completed due to several complications that arose with the operation of the power supplies for the IEC device. In order to accomplish the first two goals, a complete (minus the power supply) IEC unit was borrowed from the Nuclear Engineering Department of the University of Illinois at Urbana-Champaign. This device will be described below.

DESCRIPTION OF CONCEPT

The IEC device studied here generates a relatively deep potential well inside a spherical, highly transparent cathode-grid, which is concentrically positioned inside a spherical vacuum vessel. When a high voltage bias is placed across the electrodes while in the presence of a background gas pressure in the mTorr range a glow discharge occurs whereby relatively monoenergetic ions are accelerated into the center of the cathode-grid. The inertia of these ions compresses the spherical beam, allowing for the confinement of fairly high densities of ions inside this inner region. Such plasmas are routinely generated, and several stable modes of operation have been observed.^{1,2} In one of these modes an intense plasma jet forms; hence, this mode is named "jet mode" for its characteristic jet that is generated inside the cathode. (See Fig. 1.)

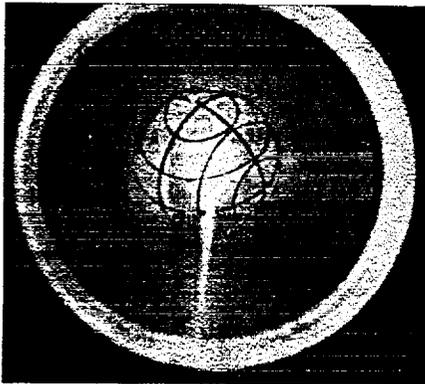


Figure 1. IEC Operation in Jet Mode.

The jet mode has been observed in certain grids with an enlarged opening. It is theorized that the enlarged hole destroys some of the symmetry of the spherical grid, allowing for an electric field to reach into the cathode-grid. This electric field will then accelerate some of the electrons inside the cathode-grid that are the result of ionization of the background gas. This resultant flow of electrons out through the cathode-grid in turn ionizes additional background gas atoms, and an intense beam of ions is formed. It is this



beam of ions that could, if focused and allowed out of the device, be used for thrust. A conceptualization of this idea has already been made.^{3,4}

Another mode of operation, called “star mode,” can be achieved in a symmetrical grid that does not have the enlarged hole described above. This mode has a fairly symmetrical flow of ions going through the cathode-grid. These recirculating ions can form a series of multiple potential wells that can contain a fusion plasma (as discussed below). (See Fig. 2.)

Figure 2. IEC in Star Mode of Operation.

HISTORICAL BACKGROUND

The approach to fusion using IEC was originally conceived by P. Farnsworth⁵ (inventor of electronic television in the US), and later studied experimentally by Hirsch⁶. However little was done to study this concept until R. W. Bussard⁷ and G. H. Miley⁸ renewed studies in the early 1990s. Each one of these investigators studied multiple potential well formation, both with theory and experiment; so a detailed description of these wells will not be given here.

The basic IEC approach pursued here (spherical devices with grids operating in the star mode) was subsequently conceived by Miley, et al.⁹ as part of an IEC-based fusion neutron source project at the U. of Illinois (UI). This configuration is now being commercialized by Daimler-Benz Aerospace Corp. (the first commercial application of a confined, fusing plasma!)¹⁰

IEC AT UNIVERSITY OF ILLINOIS

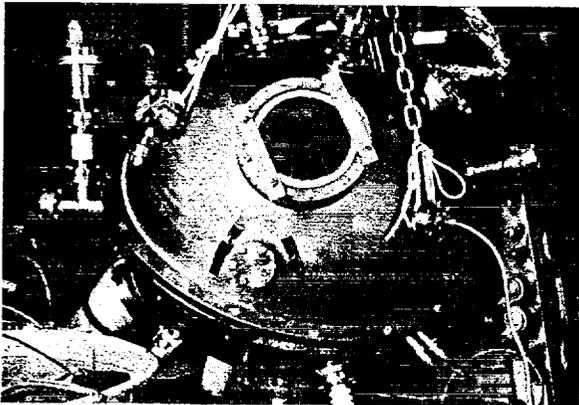


Figure 3. B-Device at the Univ. of Illinois

Research into IEC has progressed in the Fusion Studies Laboratory for over a decade now. During this time, several IEC experiments have been built and tested. These include one two-foot in diameter spherical vessel, two one-foot in diameter spherical vessels, and two cylindrical vessels, approximately six inches in diameter and four feet long. These devices have explored everything from glow discharge operation, to multiple well formation, to neutron production. Figure 3

is a photo of the two-foot vessel, named “B-Device”. Presently, research at the University is focusing on how to exploit the IEC for use in space propulsion and power.

IEC AT MARSHALL'S PROPULSION RESEARCH CENTER

The long-term goal in the Propulsion Research Center at the Marshall Space Flight Center is to construct a dedicated IEC facility. To reach that goal, two things were done this summer: 1) A small, portable IEC device was borrowed from the University of Illinois; and 2) a new, larger IEC vessel was designed and ordered. Figure 4 depicts the 1-foot in diameter IEC vessel that was borrowed from Fusion Studies Laboratory at the University of Illinois, in Urbana-Champaign (UIUC). In addition to the vessel, turbomolecular vacuum pump, and associated hardware, a complete neutron detection suite was also borrowed. The neutron sensitive



Figure 4. The borrowed IEC system set up at MSFC

portion of this suite is the large cylinder of polyethylene shown just to the left of the IEC vessel in Fig. 4. The accompanying electronics is in the rack to the right. To make this experiment operational, though, a high voltage power supply was expected to be available at the PRC. Unfortunately, a working device capable of operating the IEC at sufficient power levels was never obtained; therefore, only limited operation of the device was possible.

With this borrowed device, and the limited capabilities of the power supply that was borrowed from Auburn University (for which this author is grateful), IEC operation was demonstrated to the staff of the PRC, local Center directors, an ABC Nightly News crew, and a nationally renowned author and writer.

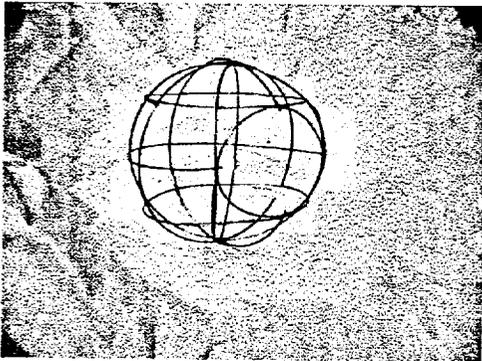
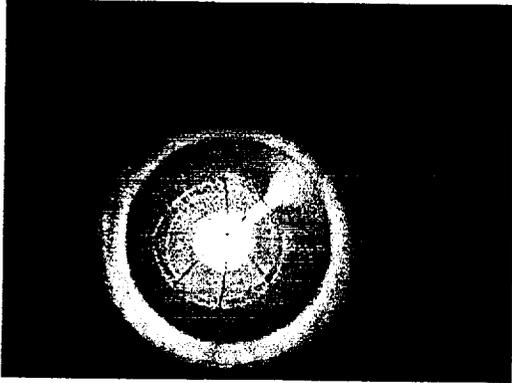


Figure 5. IEC Grid Designed for Jet Mode.

In order to investigate the use of an IEC device operating in jet mode for possible space propulsion applications, a special grid was manufactured (see Fig. 5). This grid, approximately 4" in diameter, was made with a large asymmetrical hole cut out of one side.

This grid was operated for a short time, until the

power supply overheated and conked out. But during those few minutes of operation the image in Fig. 6 was obtained. One can notice the flared out nature of this jet, as opposed to the jet shown in Fig. 1. This broadening of the jet is due to excessive electron collisions at higher pressures with the background neutral gas molecules. The discharge



in Fig. 1 was at a substantially lower background pressure. Unfortunately, at the lower pressures a higher power level is required, a power level that our power supply could not maintain. But, as can be seen in the figures, this jet might have potential as a plasma thruster.

Figure 6. IEC operation in Jet Mode.

In order to investigate further the possibilities of IEC technology in space, the PRC has ordered an advanced IEC reactor vessel. The design of the device was based on this summer's experience. This two-foot in diameter vessel (see Fig. 7) is double jacketed for liquid cooling, and is equipped multiple ports of various sizes for increased versatility.

IEC APPLICATIONS TO SPACE PROPULSION AND POWER

The IEC power unit employs a spherical configuration, wherein ions are generated and accelerated towards the center of a spherical vacuum chamber where intensive fusion reactions occur. Thus a very high fusion power density is obtained in a small volume where the ion beams collide in the center of the device. Consequently, the IEC lends itself to use either as a compact power unit for station keeping or landing site power or for space propulsion. In the former applications, the fusion energy released is converted to electricity using either advanced thermal conversion or direct-energy conversion techniques. This allows a compact unit with very high-energy conversion efficiency.

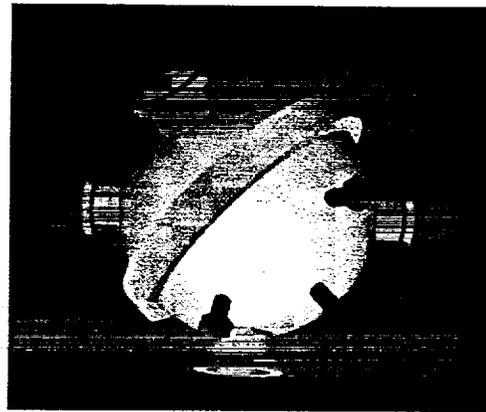


Figure 7. The newly designed IEC vessel

Alternately, the unit can be configured as a fusion propulsion unit, using one of several methods to extract directed energy for thrust. For example, virtual cathode formation in a high-density central core region, combined with a locally distorted cathode grid potential field, extracts accelerated ions into an intense quasi-neutral ion jet. The simple IEC structure combined with high fusion power density makes the IEC thruster an exceedingly high specific impulse unit, enabling deep space missions not accessible with conventional propulsion concepts. The same advantages make possible a high power-per-unit mass electrical power unit that is very attractive for a variety of on-board and landing site power application. Small-scale IEC experiments have produced encouraging results and are used here as the basis for extrapolation to the space power unit. However, critical scale-up experiments proposed for the future

are essential to verify the feasibility of the concept. The non-Maxwellian beam-beam type reactions, plus lack of cyclotron radiation due to the elimination of B-fields makes the IEC attractive for burning advanced fusion fuels, like D-³He and p-¹¹B.

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