Project Proposal: Farnsworth-Hirsch Type Fusion Reactor

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1 Introduction

In order for atomic nuclei to fuse, they must be given enough energy to overcome the Coulomb barrier. Since the energies required, 1-10 keV, correspond to high temperatures, on the order of 10^8 K, both confinement and heating of the plasma are challenging. In fusion reactors intended to break even and produce usable energy, confinement is usually achieved magnetically (tokamak) or inertially (laser ablation implosion). However, if the goal is merely to develop a reactor capable of producing fusion (not intended to reach break-even), an simpler method is possible: electrostatic inertial confinement (EIC).

In this system, known as a fusor, rather than trying to confine an ultrahot fusing plasma, or quickly imploding a fuel pellet, ions are driven electrostatically towards a focal point, where some collide with enough energy to fuse.

2 Realization

In the Farnsworth-Hirsch fusor design, ions are driven from a grounded or positively charged outer conductor to a negatively charged "cage", usually made of wire. Since deuterium cations have a charge of 1e, after traversing an electric field of (for example) 10 kV, they will have achieved an energy of 10 keV. While some of the accelerated ions will collide with the negatively-charged cage, others will pass though. In the most common design, using a spherical cage, this results in deuterium ions colliding in the center with enough energy to permit fusion (fig. 1).

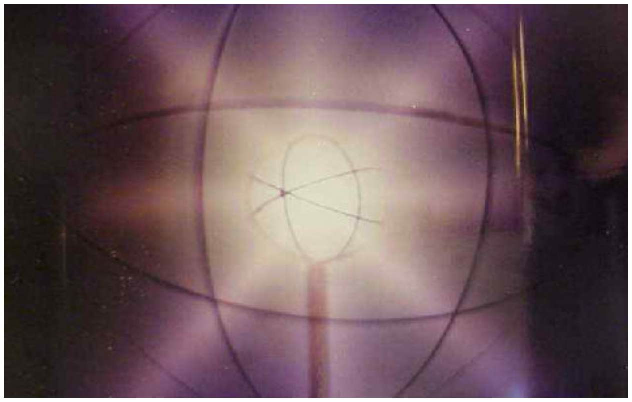

Figure 1: Fusor operating in "star mode"

3 Reactor Design

Since the fusor needs to operate in a high-vacuum environment (10^{-6} Torr or better), a significant portion of the design effort and equipment cost is devoted to vacuum pumping and maintaining vacuum integrity. The primary vessel is a spherical 12" diameter stainless steel vacuum chamber (SP1200S) manufactured by the Kurt J. Lesker Company. The primary high-vacuum pump is a Varian Turbo-V 81-T turbomolecular pump, capable of pulling down to 10^{-9} Torr. The turbomolecular pump is backed by a Varian DS-42 dual-stage rotary vane roughing pump. Pressure is monitored with a vacuum ionization gauge mounted to a port on the chamber.

To avoid degradation of the vacuum, all penetrations of the chamber are made via vacuum feedthroughs. Specifically, this includes the high-voltage feedthrough mentioned below, an 8-pin low-voltage feedthrough for power and instrumentation inside the chamber, an atmospheric bleed valve for venting the chamber to the atmosphere, and a dedicated deuterium injection port.

In the initial design, the inner grid is to be made of stainless steel wire, for good resistance to energetic ion erosion. As testing progresses, the grid may be upgraded to even more resilient materials (eg, tungsten, molybdenum alloy). This grid is suspended from a Lesker 30 kV rated high-voltage vacuum feedthrough, mounted to the top port of the vacuum chamber.

4 Project Phases

4.1 Phase I: Construction and Infrastructure

In the initial phase, all of the major components must be assembled tested to achieve the necessary vacuum. Due to the demanding nature of the high vacuum, knowledge and procedures will need to be developed for roughing, turbopumping, bake-out, and venting. In addition, instrumentation and automation will need to be developed to monitor and control the chamber environment.

4.2 Phase II: Demo Mode

Next, the high voltage is introduced. When a sufficiently high voltage is applied to the fusor under a moderate vacuum, residual atmospheric gases will ionize and collide in the grid, without actually fusing. If the vacuum and high-voltage systems are functioning properly, a "star mode" corona discharge can be produced (fig. 1). This is an indication that the fusor has been set up correctly. Since it does not require deuterium and does not produce neutrons, this mode is excellent for demonstration and teaching purposes.

4.3 Phase III: Fusion

Finally, the chamber is evacuated as much as possible, and deuterium is introduced. If all goes well, on the application of appropriate voltage, some of the deuterium ions will fuse, producing Helium-3, a neutron, and excess energy: ${}^2_1H + {}^2_1H \rightarrow {}^3_2He + {}^1_0n + 3.27$ MeV

The effort required to move from Phase II to Phase III is significant: not only must deuterium gas be procured or generated, but additional instrumentation for neutron detection, as well as neutron shielding, must be developed.

5 Safety

The predominant safety risks associated with this project are the usual ones related to high voltage and high vacuum. Only in the final phase is there radiation that needs to be shielded (neutrons). Although this is a nuclear reactor, unlike e.g. fission power plants, it is impossible for a fusor to "melt down" or enter an uncontrolled chain reaction; depletion of deuterium ions, removal of high-voltage power, or reduction of the vacuum immediately terminates the reaction. Furthermore, as a fusion reactor, it merely converts hydrogen into helium; no radioactive materials are required or produced.

6 Component Sourcing

The following drawings and BOM presume that all components are bought new. It is likely that significant cost reductions (perhaps greater than 50%) could be achieved by buying used or surplus equipment. For example, just the spherical vacuum chamber accounts for nearly $5,000 of the estimated project cost. Since high vacuum chambers and equipment are so commonly used in the scientific, R&D, and semiconductor industries, large portions of the vacuum equipment could probably be acquired as excessed matériel from technology companies.