Plasma Dynamics in a Z-Pinch Fusion Engine

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Abstract

Project Icarus is a theoretical design project for an unmanned fusion-based probe to Alpha Centauri. The project was started in 2009 and is now drafting its Final Report.

The leading design to come out of the project is a vessel dubbed “Firefly”, built around a continuous Z-pinch fusion engine. This engine is based on experimental work by Uri Shumlak at the University of Washington that shows a Z-pinch plasma can be stabilized via sufficient “shear” flow of plasma through the pinch. There are nevertheless some major differences between the Firefly drive and Shumlak’s test device:

(1) Shumlak's apparatus works in single-shot, rather than continuous, mode.

(2) Shumlak's apparatus is housed in a solid tube which serves as one of the electrodes, while Firefly has an open core with three conducting rails.

(3) Shumlak's apparatus uses an entirely different plasma injection strategy, at much lower velocities.

(4) Shumlak's apparatus doesn't actually fuse anything.

To achieve the plasma flow rate necessary to maintain plasma stability, the Firefly engine uses MPD thrusters to inject plasma at high speed into the pinch. Preliminary mathematics have been developed to describe the transition of the plasma from MPD exhaust into the Z-pinch, but confidence in this model is low.

In particular, Shumlak’s formula for calculating the pinch diameter / density is based on the premise that gas in an "assembly region" is forced into the "pinch region", where it gets compressed by the strong current of the pinch. Thus, the mass and volume in the pinch are functions of the mass and volume in the assembly region. But in a continuous-pinch model where the plasma is injected into the pinch at high speed, a new model is required to calculate the geometry of this input plasma as it encounters the pinch, as well as its temperature and density through the transition. A model is also needed to describe how the intense magnetic field of the pinch might interact / interfere with the magnetic fields in the plasma injectors.

This presentation will describe the Firefly drive and the mathematical model used to calculate critical parameters of the fusion core, with the hope that other attendees at the workshop can provide ideas for better modeling the plasma dynamics in the core. This paper is submitted for the day 1 session “Energetic Reaction Engines”.

Keywords: Z-Pinch Fusion, Firefly, Project Icarus

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