SMALL SCALE FUSION
THE PULSED HIGH DENSITY FRC EXPERIMENT*

John Slough

University of Washington
Seattle, WA 98195 U.S.A.

It is quite possible that nuclear fusion will be the only source that can provide the prodigious power demands that the world will face in the future. The difficulty however for most nuclear fusion concepts is the complexity and large mass associated with the confinement systems. Essentially, the more massive the system required to confine and heat the fusion plasma, the higher the cost to develop and operate. The challenge that the fusion community is faced with today is a consequence of this scaling. The high cost of tokamak research (and thus reactors) is primarily due to the large reactor sizes required for fusion gain with low β steady state reactors (β being the ratio of the plasma to magnetic energy density). At the other end of the spectrum, for most pulsed devices, the mass and complexity of the fast energy delivery systems becomes the problem. In particular, the ability to rapidly and repetitively pulse these lower yield plasmas to achieve reasonable power efficiency is complicated considerably by the drivers (lasers, liners, beams etc.).

It is the contention here that a simpler path to fusion, that avoids many of these major difficulties, can be achieved by creating fusion conditions in a different regime at small scale ($r_p \sim$ a few cm). The experimental program that will be outlined takes advantage of developments in the very compact, high energy density regime of fusion employing a plasmoid commonly referred to as a Field Reversed Configuration (FRC). (1) Of all fusion reactor embodiments, only the FRC has the linear geometry, low confining field, and high plasma β, and closed field confinement required for magnetic fusion at high energy density. Most importantly, the FRC has already demonstrated the confinement scaling with size and density required for fusion at high density.(2) A fusion reactor based on the formation, acceleration, and compression of the FRC has several advantages over other high density approaches such as the Z and θ pinches. The FRC is a closed field configuration with confinement times $>> \tau_A$. The FRC can be isolated from vacuum chamber boundaries so that the plasma need not be heated to fusion temperatures on Alfvenic timescales. It need not burn amidst the high voltage pulse power apparatus employed for formation. Translatability, and of course the high β nature of the FRC are significant advantages of over toroidal magnetic systems such as the tokamak as well.

As will be described in more detail, the energy needed to achieve fusion conditions is transferred to the FRC via simple, relatively low field acceleration/compression coils, and it is believed that this process can be made repetitive and very efficient, thus avoiding the need for inefficient methods such as neutral beams to reach fusion temperatures. By operating in the small, high density regime, the requirement on the FRC closed poloidal flux is no greater than what has already been achieved, and orders of magnitude less than that required for the low density steady-state regime. Most importantly, the FRC remains in a stable regime with regard to MHD modes such as the tilt from formation through burn.

The goal of the initial Pulsed High Density experiment (PHDX) will be to form, accelerate and compress an FRC to a density of $1\text{x}10^{22}$ m^{-3} at a temperature greater than 1 keV. With the energy confinement time predicted by previous FRC scaling (3), the FRC should attain a $n\tau$ product of $5\text{x}10^{18}$ m^{-3}s, which would exceed previous FRC results by nearly an order of magnitude. The experiment will essentially be the first step, where progress towards breakeven can be made in incremental steps with additional stages of acceleration and compression based on the successful completion of this first phase.

The high density plasma fusion reactor that will be outlined here provides for a technologically appealing method for achieving fusion on a small scale. The formation of the source FRC parameters have been achieved already in past FRC experiments, and plans for improvements were detailed. Rapid acceleration of the FRC has been demonstrated ($a > 10^{10}$ m/s^2), and plans for a simpler and more efficient accelerator/compressor will be presented. The thermal conversion of translational energy without loss of confinement has also been demonstrated in previous experiments. Finally, in the reactor scenario outlined for PHD, the FRC at no time exceeds the empirical regime where stability and good confinement has been observed throughout the entire formation process through burn. The planned PHD source experiments would finally complete the stability and confinement study begun with LSX with improvements that would provide for a test of the stability limits and confinement for the FRC.

An important advantage of small scale pulsed fusion as envisioned with PHD is that the development should not require significant time or resources. The technologies involved in all aspects of the concept have been developed to the point that rapid testing and development can be accomplished. The proposed PHDX experiment, if successful, would serve as a proof of principle experiment that could be rapidly developed toward a breakeven FRC fusion experiment.

REFERENCES

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