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Slow Liner Fusion

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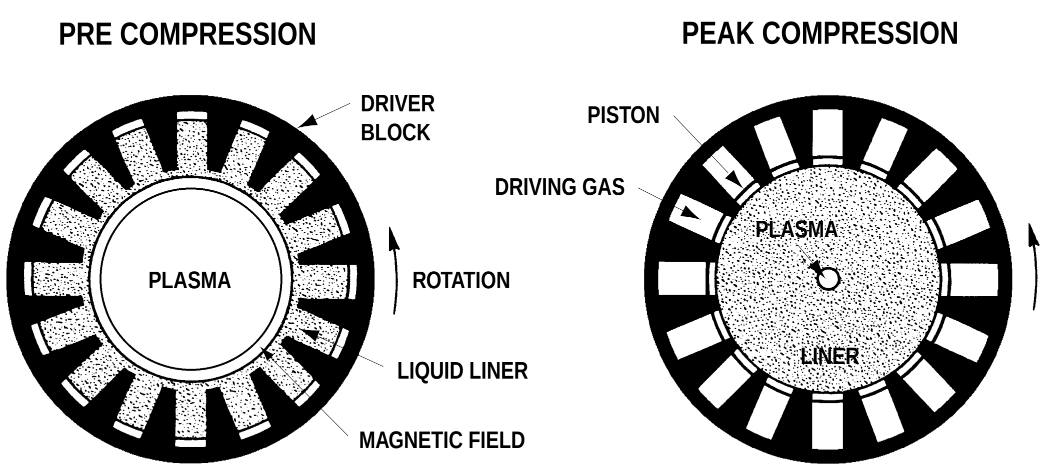
Summary

"Slow" liner fusion (~10 ms compression time) implosions are nondestructive and make repetitive (~1 Hz) pulsed liner fusion reactors possible. This paper summarizes a General Atomics physics-based fusion reactor study [1,2] that showed slow liner feasibility, even with conservative open-line axial magnetic field confinement and Bohm radial transport.

Background

Slow liner fusion (~10 ms compression rundown time) was pioneered by A.E. Robson and colleagues as the LINUS concept [3] at the U.S. Naval Research Laboratory, where its potentially nondestructive pulses were seen as more likely to lead to a compact power reactor than "fast" liner fusion (<<1 ms rundown). In the slow liner concept, a driving system ("driver block" in the figure) implodes a thick liquid liner to compress a magnetized plasma to fusion ignition, which occurs near peak pressure during the brief liner "dwell" phase. The driver might use high pressure gas acting on pistons in various geometries. The liner, which serves as a renewable first wall and blanket, tolerates larger



fusion power and neutron fluxes than conventional fusion reactors. The high neutron flux capability led the Electric Power Research Institute to sponsor the "Background Study of Liner Fusion Systems for Transmuting Fission Reactor Wastes" [1] at General Atomics.

Power producing liner reactors were studied by General Atomics [2]. The physics of high–β and wall confined plasmas compressed by thick, compressible, rotating, liquid liners was studied in detail, in order to assess reactor performance.

Slow Liner Fusion Power Reactor

The conducting liner is a vortex of liquid metal rotating at a speed chosen to stabilize the Rayleigh–Taylor instability during liner deceleration and turnaround. The liquid liner is contained within a massive structure that includes, among other things, the reversible liner driver and heat removal means. The requirements of nondestructive pressures and repetitive liner driver technologies sets liner parameters: initial vortex inner radius ~1 m, compressed radius ~0.05 m, compression time ~10 ms, and fusion burn time ~100 μs. In the simplest scaling, the energy to compress the liner and plasma grows as Q_L^2 and the fusion energy per pulse as Q_L^3, where Q_L = (fusion energy per pulse)÷(liner energy per pulse). Thus, high Q_L liner reactors are large. Typically Q_L is made < 1, but then the compression energy must be recovered with high efficiency by a reversible driver. Since liner compressibility stores a major fraction of the liner energy, and the plasma high pressure peak duration is shorter than a sound transit time across the liner, the liner compression was studied numerically using a high pressure equation of state. High energy transfer efficiency, defined as (compressed plasma energy)÷(driving energy) requires high ρc^2, low compressibility and a radially thin liner, where ρ and c are liner mass density and sound speed, respectively. Most liquids are too compressible.

The liner is made of layered immiscible liquids to combine favorable material properties. The plasma-facing layer needs high electrical conductivity, low vapor pressure and low Z, while the bulk liner must be denser and breed tritium. The inner and outer layers might be liquid Al and Pb-Li alloy, respectively. While relatively immiscible, they can be further separated by a molten halide salt layer, such as the ternary eutectic .54 LiF-.28MgF_2-.18SrF_2 (MP = 646˚C), which is chemically compatible with Al, Pb and Li.

The liner containment vessel has end holes on axis, both for injection of uncompressed plasma and because solid end walls would be destroyed by the peak pressure. The liner-compatible, high–β wall-confined plasma with an open-line axial magnetic field was studied in greatest detail. Plasma and impurity transport and radiation were studied by a 1 1/2–D code [4] implementing the full Braginskii classical multispecies transport. Axial free streaming loss is reduced by inertial end tamping by dense, cold plasma. End loss is then dominated by the electron thermal conduction, $q_{e_\parallel} \sim T_e^{7/2}$, which is only important near burn temperatures. A major fraction of the end loss is dissipated in just a few cm of the plug [5], vaporizing part of the nearby liner and usefully adding end tamping mass. Radial transport is expected to be classical, based on θ–pinch experience, but Bohm transport is tolerable [4]. Since compression of magnetic flux is wasteful, operation is with $\beta > 1$ at peak compression and $\beta >> 10$ initially (wall confinement). Cooling at the wall decreases plasma pressure there and lets plasma and magnetic flux convect radially outward until a $\beta < 1$ boundary layer is formed [6,7]. In order to avoid excessive radial plasma transport during the slow compression, the low–β boundary must be formed by injecting initial plasma on axis and allowing it to displace magnetic flux to the wall. Cold liner material vaporized by bremsstrahlung mingles with boundary layer plasma, but the classical thermal force acts radially outward and confines impurities to the boundary layer.

A reactor scoping code [1,2] was used. An example reactor is: compressed radius = 0.04 m, volume compression ratio = 400, T = 6 keV, β = 6, liner length = 90 m, fusion energy per pulse = 7.65 Gj, injected plasma energy = 0.235 Gj, Q_L = 0.63, η_{net} = 0.26 = (power for sale)÷(nuclear power). The liner was driven by He gas at 680 bar. The initial plasma might be injected by a deflagration plasma source [8], which produces a directed, high power plasma stream. Heat removal and vacuum pumping concepts are discussed in [1]. Despite the open confinement, the liner length is not much greater than the projected ITER plasma circumference of ~50 m.

Slow liner fusion reactors tolerate very conservative physics assumptions, eg. Bohm transport and open magnetic lines, but the engineering is challenging. They become more attractive if they can operate with a magnetically closed plasma, such as an FRC [1–3].

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