Simulation of Field Reversed Configurations

NIMROD Team Meeting 6/4/2020

Simon Woodruff, Thomas Meyer, James Stuber
Compact Fusion Systems, 2778 Agua Fria Street, Unit 4, Santa Fe, NM 87507

Work supported by a seed investment from Wurzel, Dahl and Handley, also by the NM Economic Development Department under the Small Business Assistance Program, and by ARPA-E under contract DE-AR0001174
Introduction and background

• Compact Fusion Systems, Inc is being spun out of Woodruff Scientific, Inc, founded in October 2017
• Has found 120k USD seed fund from the New Mexico Economic Development Department, and angel investors.
• We are developing a liner compression concept originally developed by Turchi and supported recently by ARPA-E [1]
• Also based on costing and reactor design by Woodruff and Miller [2-3]
• And separately by Miller [4].
• Draws also on work on plasma compression work by Sieck [5] and Woodruff [6].
Motivation is to explore a near-term revenue possibility for fusion, as a development stage towards a power-producing system.
Origins in the LINUS program at NRL 1972 - 1980
Concept
Mechanical and electrical engineering for the Proof of Principle is ongoing.
Bias bank and 4 full shiva star modules and railgap switches and charging supplies - items that we will be shipping to our lab this month.
Compressor is still in the concept design phase
Analytic modeling starts with Turchi et al 2017

Analytic modeling developed to explore the compression of the FRC plasma with a prescribed liner run-in for a range of parameters.

Work to follow:
--inform compression with MHD modeling that includes anisotropic, and temperature-dependent thermal conduction.
--fully explore range of operating regimes.
We are using CORSICA to explore 2D physics

Internal profiles are specified in CORSICA according to the following formula:

\[ n_e(r) = (n_{e,\text{peak}} - n_{e,\text{edge}}) \sqrt{1 - (r/a)^{\alpha_{n_e}}} + n_{e,\text{edge}} \]

\[ T_e(r) = (T_{e,\text{peak}} - T_{e,\text{edge}}) \sqrt{1 - (r/a)^{\alpha_{T_e}}} + T_{e,\text{edge}} \]

Varying ashp from 5 to 1 gives a range of possible profiles. The fusion power is highly sensitive to the form of this profile.

Routines used previously for SSPX energy confinement scaling to obtain Chi (Psi).
Cygnus is being used as part of the design work

Cygnus is a 2D extended MHD code which captures both plasma and electrical engineering features of pulsed formation. Resistivity, anisotropic thermal conductivity and viscosity are included. Geometry is represented on a rectangular, non-uniform r,z mesh using cut-cells to capture shaped boundaries.

The domain is 5 m by 0.35 m. Two conical q-pinch coils are arranged outside dielectric walls. The central cylindrical wall is a conductor (resistivity of stainless steel) and the end plates are also stainless steel. Generic circuit model:
NIMROD is a 3D extended 3D MHD code, FE in rz plane, spectrally resolved in azimuthal direction. Includes Braginskii transport (anisotropic and temperature-dependent thermal conduction).

Simulations for translation and merging use ICs like Turchi TPS ($r_{\text{sep}} \sim 5\text{cm}, 2.1\text{T}, 600\text{eV}, 7.9 \times 10^{21}\text{m}^{-3}$)

Coils along z ramped to first accelerate plasma peristaltically, and then produce mirror fields to trap translated plasma.
NIMROD: compression cases with Turchi et al ICs

NIMROD magnetic compression cases running in 2D with relevance ICs.

Coils all ramped at the same time - 5, 10, 20, 40μs ramp rates all give compression, and pressure seen to increase.
Work done: compression w/ liner (liquid metal liner approximated as a plasma using profiles)

NIMROD simulation cases with a liner are running - not yet in the relevance geometry or with right ICs.

Liner is modeled as a cold dense plasma and is forced to move by ramping external coils.
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Modification of the BCs at the ends of the FRC to simulate ‘end shorting’ mitigation electrodes

Stability of the plasma to n=2 rotational mode is understood to be provided by counteracting the effects of ‘end-shorting’ (wherein a velocity shear is produced between open and closed field lines resulting in instability).

We have set up BCs to emulate electrostatic biasing of annular electrodes to produce azimuthal flows from E xB (case is with 3 external coils and 3 electrodes, although many configurations exist).
Work upcoming

• Cygnus: complete design of system
• Complete campaigns for magnetic compression and liner compression
• Integrate BC mods into code version (vintage 2009-2011)
Summary

• Compact Fusion Systems is a new company, bringing together Woodruff, Turchi, Miller and Sieck, supported also by staff at Woodruff Scientific and US collaborators.
• Our resources are primarily modelling and simulation, but we also have a lab and will be building prototypes.
• Plasma systems are at prelim EDR stage
• Compressor is at the CDR stage.
• Goal is an engineering design for a 1MW fusion neutron source as part of CRP, as development stage in path towards power production.
References


