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One Dimensional Burn Computations for RFPR*

by

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I. Introduction

Previous studies[1] of the Reversed Field Pinch Reactor (RFPR) have been done with a zero-dimensional or "point-properties" formulation which averages all plasma profiles over the radius. In order to allow a closer examination of the RFPR performance and explore other phenomena, a more realistic one-dimensional (radial) plasma model (RFPBRN) has been developed[2] and applied to RFPR.

The earlier global model assumes flat temperature profiles, classical particle confinement, and magnetic field profiles determined through a pressure balance model alone. In contrast, the one-dimensional model determines the temperature and field profiles self-consistently and allows for instability induced transport as well. It also checks the plasma profiles' local and global stability characteristics. A major objective of this study was to determine how these additional physical effects would influence the RFPR design. Also, this new code allowed a more detailed optimization of the RFPR. Both aspects of the study are discussed here.

II. The Model

RFPBRN is a three fluid (ions, electrons, and alphas) one-dimensional, Lagrangian mesh transport and stability code. A quasi-static assumption is used so the plasma evolution can be followed on a resistive time scale. Linear ideal MHD stability is then periodically monitored as the profiles evolve in time.

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DISCLAIMER

The solution is found by integrating the temperature, density, and field profiles forward in time and then adiabatically readjusting the mesh to satisfy pressure balance. A variable time step predictor-corrector numeric technique is used to solve the diffusion section. The degree of implicitness for the numerics is controlled externally.

Transport coefficients are assumed to scale classically[3] except for thermal conduction which, based on a review of data from Zeta experiments, is taken to be ~ 1/200th Bohm. The perpendicular resistivity also assumes Bohm-like scaling in regions where Suydam's stability criterion[4] is violated. The modeling in these regions is that of Christiansen and Roberts[5].

MHD stability is monitored for both global and local modes. Local stability is monitored using Suydam's criterion while gross modes are checked using Newcomb's form of the ideal MHD energy principle[5]. The energy principle is minimized directly by using a Rayleigh-Ritz trial function expansion with arbitrary coefficients. The technique has the advantage that is shows whether the plasma is unstable to modes with wide (non-localized) eigenfunctions as well as determining the plasma's absolute stability characteristics.

III. Results

A. Zero-Dimensional and One-Dimensional Comparison

In order to match the global model as close as possible, the plasma edge was required to be the reversal point and the radius varied as:

$$r_p\,(t) = r_p\,(t=o)/\sqrt{1-\beta_\theta(t)} \qquad (1)$$

Initial conditions for temperature, density and field profiles were also taken consistent with the global model's pressure balance assumptions[6].

Results generally showed similar trends, the principle difference being that the 1-D code ignited faster, burned out quicker, and had lower

fractional burnup (see Fig. 1). All of these features can be attributed to profile effects. The lower burnup resulted in an overall reduction in the energy gain factor Q_p to about 3/5's of that predicted by the 0-D code. While this is a significant difference, the agreement is still considered "good" in view of the many differences between the two codes (See Table I).

Inclusion of Suydam induced turbulent transport flattened the density profiles but had little effect on plasma performance. The reason this effect was small is that the stable outer region provided confinement while the Suydam induced energy transport was already dominated by the assumed Bohm-like thermal conductivity (See Table II).

B. Optimized Burn

In view of the reduced energy gain predicted by the 1-D model, a decision was made to use it to optimize Q_p. The density was raised to increase the power level near the global simulation parameters. The toroidal and poloidal fields were then reduced to the marginal amount required to ignite the plasma. Poloidal β and global stability were checked to see if the plasma maintained stability (which it did).

The results of the optimization are shown in Table I where it is seen that Q_p was increased by a factor of two. The principle reason that Q_p was doubled is that the radially varying temperature profile allows ignition on the magnetic axis which then propagates radially through the plasma. This allows the current (magnetic field energy) required for ignition to be lower which in turn raises Q_p.

Summary

Studies of the RFPR have been done using a one-dimensional three fluid transport and stability code. Results have verified trends predicted by

previous global studies. However, inclusion of profile effects, principally centerline ignition, has enabled the RFPR design to be optimized to obtain Q_p's as high as 20. Assuming classical parallel resistivity, global MHD stability can be maintained throughout the entire burn.

References

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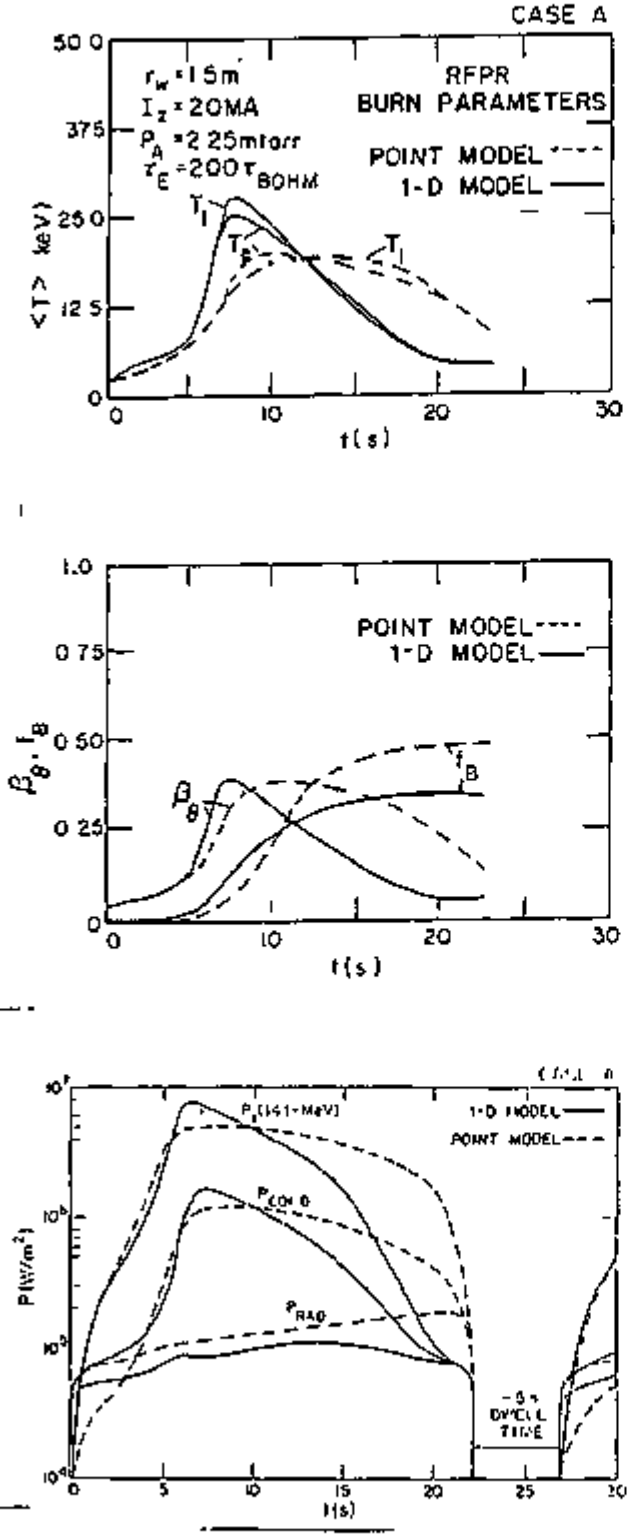

Figure 1. Global Parameters and wall load for 1-D and point model comparison.

Table 1 Comparison of Energy Balance for Zero- and One-Dimensional Burn Models

PARAMETER (MJ/m)	ZERO-D CASE A	ONE-D[a] CASE A	ONE-D[b] CASE A (OPTIMIZED)
Burn time t_B(s)	21.6	21.6	22.0
Initial plasma energy, U_{pi}	0.08	0.7	9.9
Final plasma energy, U_{pf}	2.5	1.9	1.6
Radiation energy, U_{RAD}	22.1	14.3	19.3
Ohmic heating energy, U_{OH}	7.1	8.5	8.9
Plasma energy loss (conduction), U_{CON}	177.5	93.0	144.7
Plasma expansion energy, U_{pv}	0.7	1.1	0.0
Magnetic field energy inside first wall at end of burn cycle, U_{Bf}	51.0	45.0	30.6
Fusion neutron energy, U_n(14.1 MeV)	626.5	410.0	644.2
Q_p (fusion energy)/(ohmic + field energy)	4.4	9.3	20.4

[a] Radius forced to follow zero-dimensional case

[b] Fixed plus a radius, Dohm conduction

Table 2 Comparison of Energy Balance for Nonturbulent and Turbulent Transport

PARAMETER (MJ/m)	0-D[a] CASE B	1-D[b] CASE B
Burn time t_B(s)	24.0	25.0
Initial plasma energy U_{pi}	0.3	0.3
Final plasma energy, U_{pf}	3.0	3.1
Radiation energy, U_{RAD}	8.3	13.5
Ohmic heating energy, U_{OH}	12.4	12.4
Plasma energy loss (conduction), U_{CON}	153.2	114.3
Plasma expansion energy, U_{pv}	0.0	0.0
Magnetic-field energy inside first wall at end of burn cycle U_{Bf}	45.8	45.5
Fusion neutron Energy, U_n (14.1 MeV)	533.5	664.7
Q_p (fusion energy)/(ohmic + field energy)	11.1	10.1

[a] Fixed plasma radius, no Snyder turbulence

[b] Fixed plasma radius, Snyder turbulence