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SOME RECENT COMPUTATIONAL RESULTS ON MIRROR CONFINEMENT

M. E. Rensink, J. Killeen and A. A. Mirin

March 4, 1974

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SOME RECENT COMPUTATIONAL RESULTS ON MIRROR CONFINEMENT

M. E. Rensink, J. Killeen and A. A. Mirin

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March 4, 1974

ABSTRACT

The two-dimensional Fokker-Planck code is used to study mirror confinement as a function of mirror ratio and neutral beam injection angle.

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*Work performed under the auspices of the U.S. Atomic Energy Commission

INTRODUCTION

This note presents some preliminary computational results on the steady-state equilibrium and stability properties of a mirror-confined plasma sustained by neutral injection. All results were derived from the solution of the Fokker-Planck equations using the newly-developed HYBRID code [two-dimensional (v, θ) ions; one-dimensional (v) electrons]. The steady-state particle distribution functions, which include the effects of an ambipolar potential, allow one to calculate the pressure tensor components $(p_{\parallel}, p_{\perp})$ as a function of magnetic field strength along a flux tube. These results are then used in the MHD stability conditions,

$$B + 4\pi \frac{dp_{\perp}}{dB} > 0 \quad (\text{mirror mode})$$

$$B - 4\pi \frac{dp_{\parallel}}{dB} > 0 \quad (\text{firehose mode})$$

to determine the maximum stable beta values, where β is defined by

$$\beta \equiv \frac{8\pi p_{\perp}}{8\pi p_{\perp} + B^2} \bigg|_{\text{mid-plane}}$$

and similarly for $\beta_{\parallel}$. The equilibrium pressure balance condition for a needle-shaped plasma,

$$B_{\text{vac}}^2(B) = B^2 + 8\pi p_{\perp}(B)$$

then gives the relation between the vacuum magnetic field and the magnetic field with plasma present; in particular,

$$R_{\text{vac}} = R \sqrt{1 - \beta_{\perp}}$$

where R_{vac} is the vacuum mirror ratio.

RESULTS

Only two input parameters are varied during this series of runs:

- (1) the net mirror ratio, R ; and
- (2) the neutral beam injection angle, θ_0 , as measured at the mid-plane.

Other input parameter values common to all runs are:

$$J = 2 \times 10^{15} \text{ particles/cc/sec} \quad (\text{source current})$$

$$m = 2 \text{ (deuterium)}$$

$$E_0 = 100 \text{ keV} \quad (\text{ion source energy})$$

$$E_{oe} = 20 \text{ eV} \quad (\text{electron source energy})$$

The quantities appearing in the summary tables are:

$$\bar{E}_i = \text{mean ion energy (keV)}$$

$$\bar{E}_e = \text{mean electron energy (keV)}$$

$$\phi_m = \text{ambipolar potential between mid-plane and mirror (keV)}$$

$$n = \text{mid-plane ion density (particles/cc)}$$

$$p_{||} = \text{parallel pressure (electron + ions) at mid-plane (dynes/cm}^2\text{)}$$

$$p_{\perp} = \text{perpendicular pressure (electrons + ions) at mid-plane (dynes/cm}^2\text{)}$$

$$B_m = \text{magnetic field strength at the mirrors (kilogauss)}$$

$$n\tau = \text{particle confinement parameter (cm}^{-3} \text{ sec)}$$

$$\beta_{\perp} = \text{mid-plane value of } \beta_{\perp} \text{ at the MHD stability limit}$$

$$\beta_{||} = \text{mid-plane value of } \beta_{||} \text{ at the MHD stability limit}$$

$$R_v = \text{vacuum mirror ratio (derived from } R \text{ and } \beta_{\perp}\text{)}$$

NOTE: The set of values given for $(n, p_{||}, p_{\perp}, B_m)$ correspond to the MHD stability limit for the particular source current used in our runs. These results can be scaled to

arbitrary ~~source~~ currents and hence to arbitrary values of B_m by noting that $(n, p_{||}, p_{\perp})$ scale approximately as B_m^2 .

Some of the results given in these tables are plotted in Figures 1-3 .

Other output information available from each run is exemplified by Figures 4 - 8 (Run #40 A). This data can be combined with an assumed spatial profile for $B_{vac}(z)$ to yield information on spatial gradients, adiabaticity, total number of particles, etc. Further details and analysis will be presented in a subsequent report.

TABLE 1

R = 2

$\theta_{LC} = 45.0^\circ$

<u>RUN #</u>	<u>40 A</u>	<u>40 B</u>	<u>40 C</u>	<u>40 D</u>	<u>40 E</u>
θ_o	90°	80°	70°	60°	50°
$\bar{E}_i$	111.843	111.215	108.557	98.530	78.193
$\bar{E}_e$	9.724	9.480	8.641	6.780	3.475
ϕ_m	31.855	30.931	28.019	21.203	9.900
n	$1.251 + 14$	$1.210 + 14$	$1.085 + 14$	$8.307 + 13$	$3.920 + 13$
$p_{ }$	$3.588 + 6$	$3.678 + 6$	$3.931 + 6$	$3.688 + 6$	$2.142 + 6$
$p_{\perp}$	$2.242 + 7$	$2.141 + 7$	$1.828 + 7$	$1.209 + 7$	$4.035 + 6$
B_m	72.191	59.856	42.741	31.226	22.000
$n\tau$	$7.825 + 12$	$7.320 + 12$	$5.886 + 12$	$3.450 + 12$	$7.683 + 11$
$\beta_{\perp}$	.302	.375	.502	.555	.456
$\beta_{ }$	.065	.094	.178	.275	.308
R_{vac}	1.671	1.581	1.412	1.334	1.475

TABLE 2

R = 5

$\theta_{LC} = 26.6^\circ$

<u>RUN #</u>	<u>41 A</u>	<u>41 B</u>	<u>41 C</u>	<u>41 D</u>
θ_o	90°	70°	50°	30°
$\bar{E}_i$	106.662	104.685	976.658	68.169
$\bar{E}_e$	13.696	13.167	10.695	3.778
ϕ_m	46.215	44.390	35.005	10.504
n	2.026 + 14	1.931 + 14	1.507 + 14	4.612 + 13
$P_{ }$	1.074 + 7	1.153 + 7	1.200 + 7	4.513 + 6
$P_{\perp}$	3.337 + 7	3.040 + 7	1.995 + 7	3.038 + 6
B_m	130.173	91.786	48.574	24.358
n τ	2.052 + 13	1.864 + 13	1.136 + 13	1.064 + 12
$\beta_{\perp}$	.553	.694	.842	.763
$\beta_{ }$	.285	.462	.762	.827
R_{vac}	3.343	2.766	1.990	2.435

TABLE 3

R = 10

$\theta_{LC} = 18.4^\circ$

<u>RUN #</u>	<u>42 A</u>	<u>42 B</u>	<u>42 C</u>	<u>42 D</u>	<u>42 E</u>
θ_o	90°	70°	50°	30°	25°
$\bar{E}_i$	100.325	100.295	97.223	79.357	73.460
$\bar{E}_e$	15.133	14.753	13.021	7.756	5.872
ϕ_m	51.076	49.549	43.089	23.622	17.027
n	2.396 + 14	2.308 + 14	1.963 + 14	1.083 + 14	7.802 + 13
$p_{ }$	1.507 + 7	1.611 + 7	1.759 + 7	1.169 + 7	8.965 + 6
$p_{\perp}$	3.639 + 7	3.410 + 7	2.558 + 7	9.158 + 6	5.350 + 6
B_m	196.636	162.404	83.208	40.556	50.839
n τ	2.870 + 13	2.663 + 13	1.927 + 13	5.864 + 12	3.044 + 12
$\beta_{\perp}$	.703	.765	.903	.933	.839
$\beta_{ }$	.495	.606	.865	.947	.897
R_{vac}	5.451	4.851	3.118	2.583	4.012

TABLE 4

R = 20

$\theta_{LC} = 12.9^\circ$

<u>RUN #</u>	<u>43 A</u>	<u>43 B</u>	<u>43 C</u>	<u>43 D</u>	<u>43 E</u>
θ_o	90°	70°	50°	30°	20°
$\bar{E}_i$	96.058	96.071	94.452	83.755	75.033
$\bar{E}_e$	15.968	15.670	14.364	10.401	7.340
ϕ_m	54.218	53.182	47.587	32.649	21.679
n	2.627 + 14	2.563 + 14	2.277 + 14	1.550 + 14	1.017 + 14
$P_{ }$	1.816 + 7	1.931 + 7	2.148 + 7	1.786 + 7	1.309 + 7
$P_{\perp}$	3.778 + 7	3.578 + 7	2.857 + 7	1.422 + 7	6.888 + 6
B_m	282.353	250.898	136.029	62.875	116.414
n τ	3.477 + 13	3.284 + 13	2.592 + 13	1.201 + 13	5.171 + 12
$\beta_{\perp}$	.827	.851	.939	.973	.836
β	.696	.755	.921	.978	.907
R_{vac}	8.330	7.719	4.921	3.281	8.099

FIGURE 2 A

FIGURE 2 B

FIGURE 3 A

FIGURE 3 B

TIME= 6.216E-01 SEC.

DENSITY= 1.251E+14/CC. ION E=111.843KEV

DENSITY= 1.250E+14/CC. ELE E= 9.724KEV

AM PT= 31.855KEV

ION DISTRIBUTION

FIGURE 4

ELECTRON DISTRIBUTION FUNCTION

TIME= 6.216000E-01 SECONDS

FIGURE 5

N OF PSI - TOP
PHI OF PSI - BOTTOM

TIME= 6.216000E-01 SECONDS

FIGURE 6

PPAR OF PSI - TOP
PPERP OF PSI - BOTTOM

TIME= 6.216000E-01 SECONDS

FIGURE 7

PSIVAC OF PSI

$\frac{B_{vac}}{B_0}$

EKM= 1.929400E-08 ELM= 1.000000E+90
 RVAC= 1.671012E+00
 BETMAX= 3.019300E-01 BETA0= 9.900000E-01
 KTRPP= 1.792787E-07 ERCS = 1.119093E+02 KEV

TIME= 6.216000E-01 SECONDS

FIGURE 8

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