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TITLE: ROTATIONAL INSTABILITIES IN THE FRC: RESULTS OF HYBRID SIMULATIONS

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ROTATIONAL INSTABILITIES IN THE FRC:
RESULTS OF HYBRID SIMULATIONS

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Simulations of rotational instabilities in the Field Reversed Configuration (FRC) using our quasineutral hybrid simulation code, AQUARIUS, have shown that $m = 2$ instabilities can occur for levels of ion rotation well below thresholds predicted by previous theory.[1,2]

AQUARIUS is a fully nonlinear, two-dimensional simulation code. No axial variation is allowed (i.e., $k_z = 0$). Ions are treated as particles and electrons are considered to be a massless fluid. The electric and magnetic fields are described by the Darwin (nonradiative) version of Maxwell's equations. Square conducting wall boundaries are used. We assume that the plasma is initially in a rotating rigid rotor equilibrium, with parameters similar to those of FRC experiments after ion spin-up has occurred. Any unstable mode will be naturally excited by the thermal noise in the initial equilibrium.

We define ω_i to be the mean ion rotation frequency, ω_e to be the mean electron rotation frequency, and $\omega_* \equiv \omega_e - \omega_i$ to be the relative drift frequency. As in previous papers,[1,2] we use the parameter $\alpha \equiv -\Omega_i/\omega_*$ and the parameter β_0, the "beta-on-axis," defined by $\beta_0 = 8\pi n(0)T_i/B_0^2$. T_i is the ion temperature, $T_i = m_i v_t^2/2$, and B_0 is the external magnetic field. For nonreversed theta pinch equilibria our simulations show similar behavior to that predicted by finite Larmor radius (FLR) theory.[1] No instabilities have been observed for $\alpha < 1.0$ and for larger values of α

*Current address: Los Alamos National Laboratory, Los Alamos, New Mexico 87545 growth rates are comparable to those predicted by Freidberg and Pearlstein[1] and by Seyler.[2]

For reversed (FRC) equilibria we find unstable $m = 2$ modes in a range previously thought to be stable, $\alpha < 1.0$. Figure 1 shows growth rates for the $m = 2$ mode as a function of α. For the results of Fig. 1, $\Omega_* = 0.05\ \omega_{ci}$ and field-reversal is 60%, i.e., $|B_z(0)/B_0| = 0.6$. For $\alpha = 0.0$, in this case, 60% field-reversal corresponds to $\beta_0 = 0.65$. We fix $|B_z(0)/B_0|$ rather than β_0 because this is consistent with measurements in the PIACE experiment at Osaka[3] in which $|B_z(0)/B_0|$ does not change significantly during the plasma lifetime, indicating that β_0 decreases as spin-up occurs. The entire range of α shown in Fig. 1 is predicted to be stable by FLR theory. These new results, with low unstable values of α, are consistent with measurements of carbon impurity rotation in FRX-B.[4] The maximum radial perturbation in the unstable modes of our FRC simulations has been found to occur near the field null, where resonant ion effects would be strongest. This is in contrast to the nonreversed case where the maximum perturbation is near the plasma edge. Our results are an indication that, as in other configurations,[5] the destabilizing contribution of resonant ions[2] may prevent absolute finite Larmor radius stabilization from occurring.

An example of a long simulation run showing nonlinear behavior is shown in Fig. 2. At long times both the real part of the frequency and the growth rate are found to decrease. These observations are consistent with both the PIACE and FRX-B experiments.

We have varied β_0 to see the effect of profiles that are more sharply peaked near the field null. Simulations show that decreasing β_0 (i.e., reduced compression) increases the growth rate of the $m = 2$ mode for a fixed value of α. However, this result should not imply shorter lifetimes for reduced compression cases since as β_0 is reduced it should take longer for spin-up to reach a given value of α. Simulations have also shown that for low values of β_0 there exist unstable modes with $m > 2$.

The most recent results from AQUARIUS have been with increased values of $S \equiv R/\rho_i$, where R is the major radius and ρ_i is the ion Larmor radius in the external magnetic field. Our FRX-B simulations used $S \sim 10$. For cases where $S = 31$, similar to FRX-C, we find much lower growth rates. This is presumed to be due to a reduction in the destabilizing resonant ion effects. For a case with $\alpha = 1.0$, $|B_z(0)/B_0| = 0.82$, and $\Omega_* = 0.005\ \omega_{ci}$, the m = 2 growth rate is found to be $\gamma = 0.0026\ \omega_{ci}$ and the m = 3 growth rate $\gamma = 0.0072\ \omega_{ci}$. These are approximately a factor of ten lower than for FRX-B parameters. These results indicate that the plasma lifetime should increase for larger values of S, not only because of the expected reduction in spin-up, but also because of a reduction in the growth rates of rotational instabilities.

References

1. J. P. Freidberg and L. D. Pearlstein, Phys. Fluids 21, 1207 (1978).

2. C. E. Seyler, Phys. Fluids 22, 2324 (1979).

3. S. Ohi, et al., Proc. of Third Symposium on Physics and Technology of Compact Toroids (Los Alamos, 1980).

4. R. K. Linford, et al., Proc. of Seventh IAEA Conf. (Innsbruck, 1978).

5. C. E. Seyler and J. P. Freidberg, Phys. Fluids 23, 331 (1980).

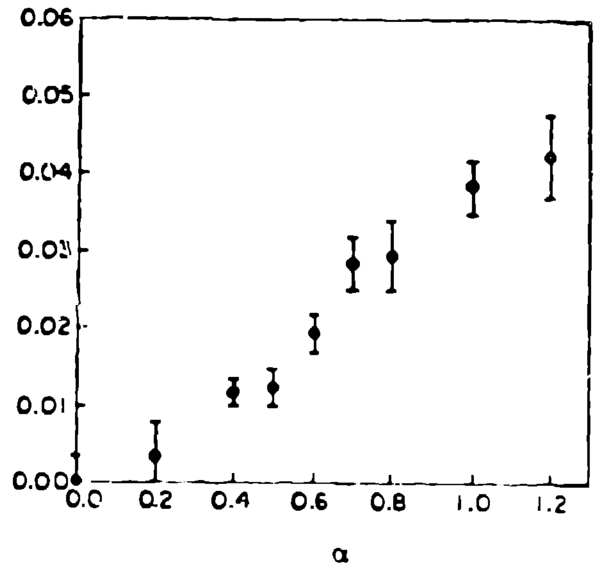

Fig. 1. Growth rates obtained from simulation for the m = 2 mode as a function of α. $|B_z(0)/B_0| = 0.6$ and $\Omega_* = 0.05\ \omega_{ci}$. β_0 varies from 0.41 for α = 1.2 to 0.65 for α = 0.0.

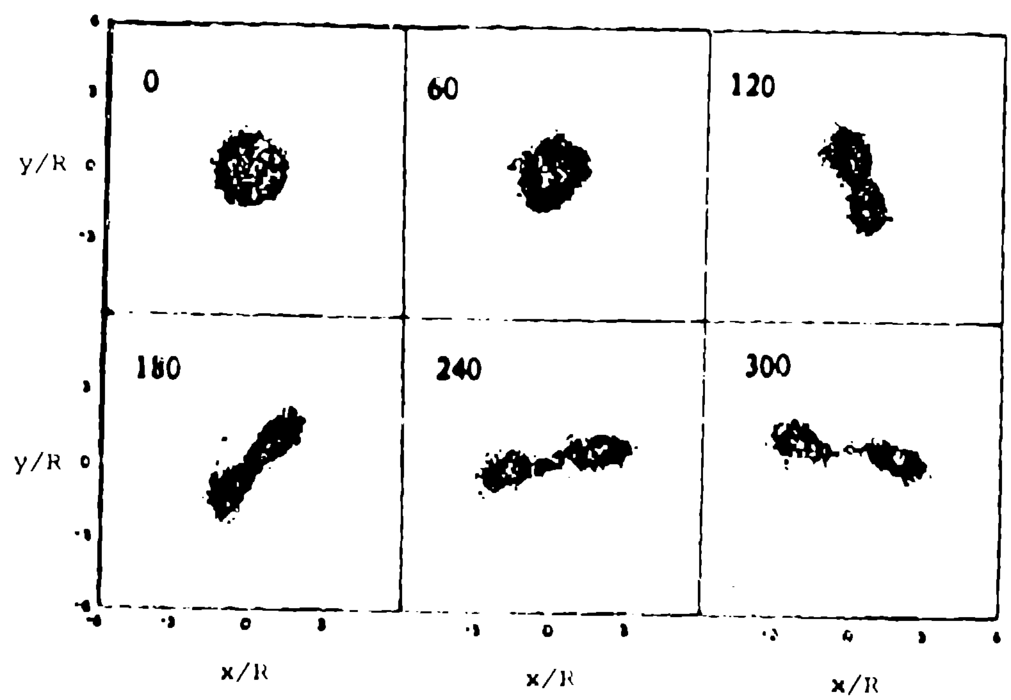

Fig. 2. Particle positions in the r = 0 plane for an FRC with α = 1.0, β_0 = 0.49, and $\Omega_* = 0.05\ \omega_{ci}$ at time intervals of 60 ω_{ci}^{-1}, from t = 0 to t = 300 ω_{ci}^{-1}. These frames correspond to 1.6 μs intervals for FRX-B parameters.