Comments® on
PLASMA PHYSICS AND CONTROLLED FUSION

CONTENTS Vol. XI, No. 5 (1988)

Comments® on Plasma Physics and Controlled Fusion

A Journal of Critical Discussion of the Current Literature

Comments on Modern Physics: Part E

Volume XI
Number 6(1988)

CPCFBJ 11(6) 269–318(1988)
ISSN 0374-2806

Comments® ON PLASMA PHYSICS AND CONTROLLED FUSION

A Journal of Critical Discussion of the Current Literature

Coordinator
BURTON D. FRIED
Department of Physics
University of California, Los Angeles
Los Angeles, California 90024

Aims and Scope

***Comments®* on Plasma Physics and Controlled Fusion** is a bimonthly journal devoted to critical commentaries on significant current developments appearing in scientific literature, featuring columns in the fields of plasma physics and controlled fusion by a panel of eminent correspondents.

COMMENTS® ON MODERN PHYSICS
L. LEDERMAN and J. WENESER, *Series coordinators*

Part A: *Comments®* on Nuclear and Particle Physics
Part B: *Comments®* on Condensed Matter Physics
Part C: *Comments®* on Astrophysics
Part D: *Comments®* on Atomic and Molecular Physics
Part E: *Comments®* on Plasma Physics and Controlled Fusion

Subscription rates

Six issues per volume:
Subscription rates per volume: corporate, $260.000; university library, $174.00; individual, $87.00. Rates include air mail postage and handling charges. Individual subscription rates are available only to individuals who subscribe directly from the publisher and who pay through personal checks or credit cards.

Prices apply in North America only. All other countries will be invoiced at our current conversion rate. The subscription rates include a distribution charge of $17.00 for postage and handling. Please write to the publisher for details. Send your order to your usual supplier or directly to Gordon and Breach, Science Publishers, Inc., c/o STBS Ltd., One Bedford Street, London, WC2E 9PP, U.K. Journal subscriptions are sold on a volume basis only; single issues are not available separately. Claims for nonreceipt of issues should be made within three months of publication of the issue or they will not be honored without charge. Subscriptions are available for microform editions. Please write for details.

Distributed by STBS Ltd., One Bedford Street, London, WC2E 9PP, U.K.
Printed in the U.K. by Bell and Bain Ltd., Glasgow.

AUGUST 1988 Issue

Can Plasma Spin-Up in Field-Reversed Configurations Be Reduced?

If the plasma spin-up in field-revesed configurations is really due to particle losses on open magnetic field lines, a way to reduce the torque should be to introduce magnetic divertors on the separatrix.

Key Words: *field-reversed configurations, divertor, plasma spin-up, separatrix*

Several mechanisms, such as torsional waves induced by end shorting,[1] particle losses on open magnetic field lines[2–4] and velocity–space particle losses,[5] have been conjectured in order to explain the apparent angular acceleration of the plasma commonly observed in field-reversed configuration (FRC) experiments. However, the real mechanism has not been confirmed yet.

Here a combined mechanism, resulting from particle losses on open magnetic field lines and velocity–space particle losses, is adopted to qualitatively show that a net torque on the plasma should arise from particle diffusion.

Describing (in cylindrical coordinates r, ϕ, z) an axisymmetric FRC through the poloidal magnetic flux function $\psi(r, z) = 2\pi \times \int_0^r dr' r' B_z(r', z)$, where B_z is the z-component of the magnetic field, choosing $\psi < 0$ inside the separatrix ($\psi = 0$ surface) and $\psi > 0$ outside and neglecting electric fields, it is possible to show that, in the absence of collisions, a positively (negatively) charged particle can promptly escape the FRC if its canonical angular mo-

Comments Plasma Phys. Controlled Fusion
1988, Vol. 11, No. 6, pp. 269–273
Reprints available directly from the publisher
Photocopying permitted by license only

mentum, $p_{\phi\alpha} = m_\alpha v_{\phi\alpha} r + q_\alpha \psi / 2\pi c$ (where α refers to particle species), is greater (lower) or equal to zero.[6]

Supposing that at the beginning of diffusion the macroscopic rotational velocities of ions and electrons are much smaller than their thermal velocities, and that collisions giving rise to particle diffusion across the separatrix are also able to maintain there a Maxwellian-like distribution of particles, at a given instant, practically half of the ion (electron) density at the separatrix corresponds to particles with positive (negative) canonical angular momentum of the order of $(m_i K T_i)^{1/2} r_s(z)[-(m_e K T_e)^{1/2} r_s(z)]$, where $r_s(z)$ is the radius of the separatrix at z. Such particles should leak from the separatrix in a thermal transit time, with a much greater probability than particles with opposite momentum. As they escape the system, collisions should replace them, giving rise to a continuous diffusion process. For T_e comparable to T_i, owing to the difference of masses, for each electron–ion pair escaping through the separatrix a net positive angular momentum should be carried away and an opposite momentum (owing to the conservation law) should appear in the bulk of confined plasma, which should spin-up in the direction of plasma current. As diffusion goes on, the macroscopic angular velocities of the species should increase and, possibly, an unbalance between the number of ions and electrons leaking from the separatrix could arise. This should give rise to an electric field, the torque should be modified and a more quantitative analysis, beyond the aim of this Comment, could be convenient.

However, if the plasma spin-up is really due to the loss of particles with preferentially oriented canonical angular momentum on open magnetic field lines, a way to reduce the torque would be to facilitate the escape of ions (electrons) with negative (positive) momentum. This can be achieved if regions outside the separatrix, and in contact with it, of negative ψ exist (where the magnetic field lines are open or touching the wall), i.e., circular divertors. In this case no preferentially oriented canonical angular momentum is needed in order for a charged particle to escape the closed magnetic field line region, so for each ion–electron pair escaping with positive momentum there is another pair with opposite momentum that has almost the same probability to be lost in a thermal transit time. Therefore, the original spin-up mechanism is uneffective and the torque on the plasma should be strongly reduced.

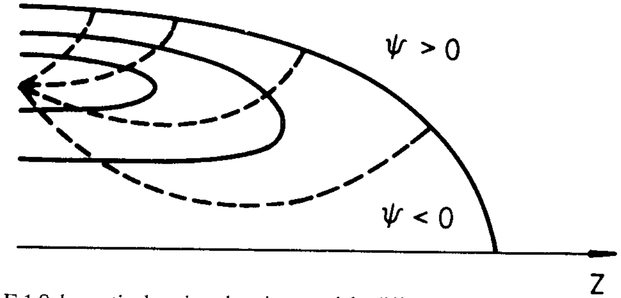

FIGURE 1 Schematic drawing showing particle diffusion streamlines (dashed lines) in a Hill's vortex-like FRC.

Using the stationary model for slowly diffusing plasmas of Kruskal and Kulsrud,[7] Auerbach and Condit have shown that the diffusion streamlines in a Hill's vortex should cross the separatrix in a spreaded way.[8] This should also be the case for all topological equivalent FRC, i.e., separatrix surrounded by the $\psi > 0$ region (see Fig. 1). However, for the Maschke–Hernegger solution[9,10] in which the separatrix is a cylindrical box with two circles where the magnetic field vanishes (such circles correspond to stagnation circles connecting the separatrix to exterior regions of positive and negative ψ), the plasma diffusion flow should be concentrated on those circles, since the loss of particles due to the finite conductivity of the plasma has been shown to become singular on any stagnation line.[11,12] (See Fig. 2.)

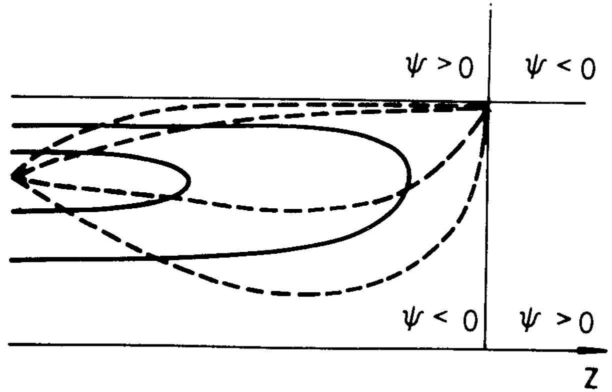

FIGURE 2 Schematic drawing showing particle diffusion streamlines (dashed lines) in a Maschke–Hernegger-like FRC in which the singularity at the stagnation circle is shown.

In principle, one circular divertor on the separatrix should be enough, and it would be very interesting to check it experimentally (the author thinks that this should be easier than to demonstrate it quantitatively on theoretical grounds).

In general, with divertors, some degradation in transport properties should be expected, and also translation would be impossible; however, the benefits could be worthwhile since, if rotation is reduced in FRC, perhaps the $m = 2$ destructive instability will not appear (or at least be delayed) and multipole stabilization will be unnecessary. Moreover, multipole stabilization also deteriorates transport since magnetic surfaces are broken.

In order to support this idea it is interesting to point out that recently, at MIT, the wobble instability in a linear mirror device has been suppressed thanks to a circular divertor in the middle of the machine.[13] Moreover, a similar proposal has been formulated by T. Hellsten,[14] in order to stabilize free boundary modes in poloidal magnetic field confinement devices.

Finally, the implementation of the divertor system could allow an experimental check of the conjecture that plasma rotation FRC is due to particle losses, with preferentially oriented angular momentum, on open magnetic field lines.

Acknowledgment

This work was performed with partial support by IAEA Research Contract No. 3504/R2/RB.

ROBERTO A. CLEMENTE*
Comisiòn Nacional de Energìa Atòmica,
Div. Fusiòn Nuclear,
1429 Buenos Aires,
Argentina

Received March 15, 1988
Contributed by Richard Siemon

*Presently on leave of absence at: Laboratorio de Plasmas/Instituto de Fìsica, UNICAMP, C.P. 6165, 13081 Campinas, SP, Brasil.

References

1. L. C. Steinhauer, Phys. Fluids **24**, 328 (1981).
2. D. C. Barnes and C. E. Seyler, in *Proceedings of the US–Japan Joint Symposium on Compact Toroids and Energetic Particle Injection* (Princeton, 1979), p. 110.
3. D. S. Harned and D. W. Hewett, Nucl. Fusion **24**, 201 (1984).
4. A. Eberhagen and W. Grossmann, Z. Physik **248**, 130 (1971).
5. M. Y. Hsiao and G. H. Miley, Phys. Fluids **28**, 1440 (1985).
6. M. Y. Wang and G. H. Miley, Nucl. Fusion **19**, 39 (1979).
7. M. D. Kruskal and R. M. Kulsrud, Phys. Fluids **1**, 265 (1958).
8. S. P. Auerbach and W. C. Condit, Nucl. Fusion **21**, 927 (1981).
9. E. K. Maschke, Plasma Phys. **15**, 535 (1973).
10. F. Hernegger, in *Proceedings of the Fifth European Conference on Controlled Fusion and Plasma Physics* (Euratom CEA, Grenoble, 1973), Vol. 1, p. 26.
11. S. P. Auerbach and A. H. Boozer, Phys. Fluids **23**, 2396 (1980).
12. R. A. Clemente and C. E. Grillo, Phys. Fluids **27**, 658 (1984).
13. R. S. Post (private communication).
14. T. Hellsten, Nucl. Fusion **22**, 565 (1982).