Conf-760944--16

NONLINEAR MHD INSTABILITIES IN ELONGATED CYLINDERS*

Glenn Bateman, H. R. Hicks, J. W. Wooten
Oak Ridge National Laboratory, Oak Ridge, Tennessee USA

Abstract

We have studied the nonlinear evolution of fixed-boundary instabilities using a 3-D ideal-MHD computer simulation. Here, we concentrate on the effect of elongation and peaked profile. It is found that the dominant process is convection around essentially fixed velocity vortex cells.

Introduction

Over the last year, we have been using a 3-D nonlinear MHD computer code [1] to study the effect of internal instabilities [2] in diffuse cylindrical pinches with square and rectangular cross section. Our computer code is very simple and fast running. It solves the primitive MHD equations as an initial boundary-value problem using an explicit leap frog difference scheme on a Cartesian grid. (We have developed more sophisticated programs to handle curved boundaries and toroidicity, but the work presented here was prepared with the original version of the code [1] completed in November, 1974). As such, our code is best suited to study large-scale internal instabilities- such as those which appear to be churning away inside tokamak discharges[3]- for high-β diffuse pinches.

The instabilities observed fall into two broad classes of behavior depending upon the equilibrium: Weak, localized instabilities churn up the central part of the plasma but leave the edge untouched. Stronger, large scale instabilities (m = 1 kink) hurl the plasma against the wall where it appears to splash. For a given periodicity length down the cylinder, and for the centrally-peaked profiles we have been considering, the central churning behavior is typical of equilibria with low current density and the instability interacts more with the wall as the longitudinal current is turned up. As the profiles become more peaked in the center, for fixed central q-value, we find that the m = 1 instability becomes more localized near the center.

Results

To date, we have used equilibria characterized by $p'(\psi) = J_{zc}(\psi/\psi_c)^{Neq}$, Neq = 1, 2, ..., $B_z = 1$, $\rho = [(1 - \rho^2_{edge}) P/P_{max} + \rho^2_{edge}]^{1/2}$ where J_{zc} = central current density and ψ_c = central value of the flux holding $\psi = 0$ at the wall. By increasing Neq we get more centrally peaked current and pressure profiles, and more shear closer to the center of the plasma. For the instabilities illustrated here, Neq = 2 has been used.

Figures 1 and 2 show typical examples of a weak - localized and a strong - broad m = 1 fixed-boundary instability. For both cases the cross section has elongation b/a = 2 and the cylinder has length $2\pi a$, where a is half the width. In each figure, the top and the bottom rows represent cross sections separated by a quarter wavelength down the cylinder. Each row shows the velocity and perturbed B-field for the linear instability and then a time sequence of contour plots for pressure (Fig. 1) and temperature (Fig. 2). In the vector plots,

*Research sponsored by the U.S. Energy Research and Development Administration under contract with Union Carbide Corporation.

arrows represent the poloidal components, closed and open circles represent components into or out of the paper. Each of the contour plots is normalized separately--the field of 5's representing the maximum value, the edge remaining at zero.

A localized instability is shown in Fig. 1 (q_c = .9, J_{z_c} = 2.418, γ_{Lin} = .228 (dimensionless units, see Ref. 4)). From the time evolution of the pressure, we see that the instability affects only the central part of the plasma. The central high pressure peak is convected around to form a small anulus (t = 5.87). Convection then continues to mix the central part of the plasma. Temperature and density respond in a similar way. The vortex cells remain essentially fixed, but there is a rapid increase in the longitudinal velocity towards the end of the sequence shown. The magnetic axis does not move noticeably: Where the shear is low, the convection around helically twisted vortex cells maps helical field lines into helical field lines. However, there are alterations in the magnitude of the B-fields which significantly change the current density.

A stronger broader m = 1 instability is shown in Fig. 2 (q_c = .6, J_{z_c} = 3.6267, γ_{Lin} = .52). The vortex cells nearly fill the plasma domain and their centers are further apart. There is more longitudinal velocity, driven by pressure gradients which develop along the magnetic field lines, because the field lines do not have the same helical pitch as the instability. The perturbed B-field, B^1, has additional vorticies (hence currents) near the top and bottom. Additional B^1 vorticies are also observed in toroidal geometry [4]. The sequence of temperature contours show steep temperature gradients developing near the wall

We have reported similar convective behavior for square cross sections (m = 1 and m = 2) in November, 1974, [2] and for rectangular cross sections with a broader current profile in April, 1975. [5]. These results appear to be confirmed by Strauss [6] using a completely different method.

Acknowledgment

We are grateful to Dr. R. A. Dory for much guidance and encouragement.

References

[1] Wooten J W and Hicks H R, Report UCC-CSD-INF-21, "Preliminary Description of the Linear and Nonlinear Ideal MHD Codes", May, 1975; see also Seventh Conference on Numerical Simulation of Plasmas, June, 1975.

[2] Wooten, J W, Hicks H R, Bateman G, Dory R A, Report ORNL-TM-4784, "Preliminary Results of the 3-D Nonlinear Ideal MHD Code", November, 1974.

[3] von Goeler S, Stodiek W, Sautoff N, Phys. Rev. Lett 33. 1201 (1974); TFR Group, Sherwood Theory Meeting, Washington (April, 1975) and Lausanne Conf. (Sept., 1975); Dunlap J, private communication (July, 1975).

[4] Bateman G, Schneider W, Grossmann W, Nuclear Fusion 14, 669-683, (1974); Fifth Conf. on Plasma Phys. and Cont. Nuc. Fus. Res. (Tokyo Conference) IAEA-CN-33/A12-1, Nov., 1974.

[5] Bateman G, Dory R A, Hicks H R, Wooten J W, Sherwood Theory Meeting, Washington (April, 1975).

[6] Strauss H R, Report FRCR No. 88, "Nonlinear, 3D MHD of Noncircular Tokamaks", (May, 1975).

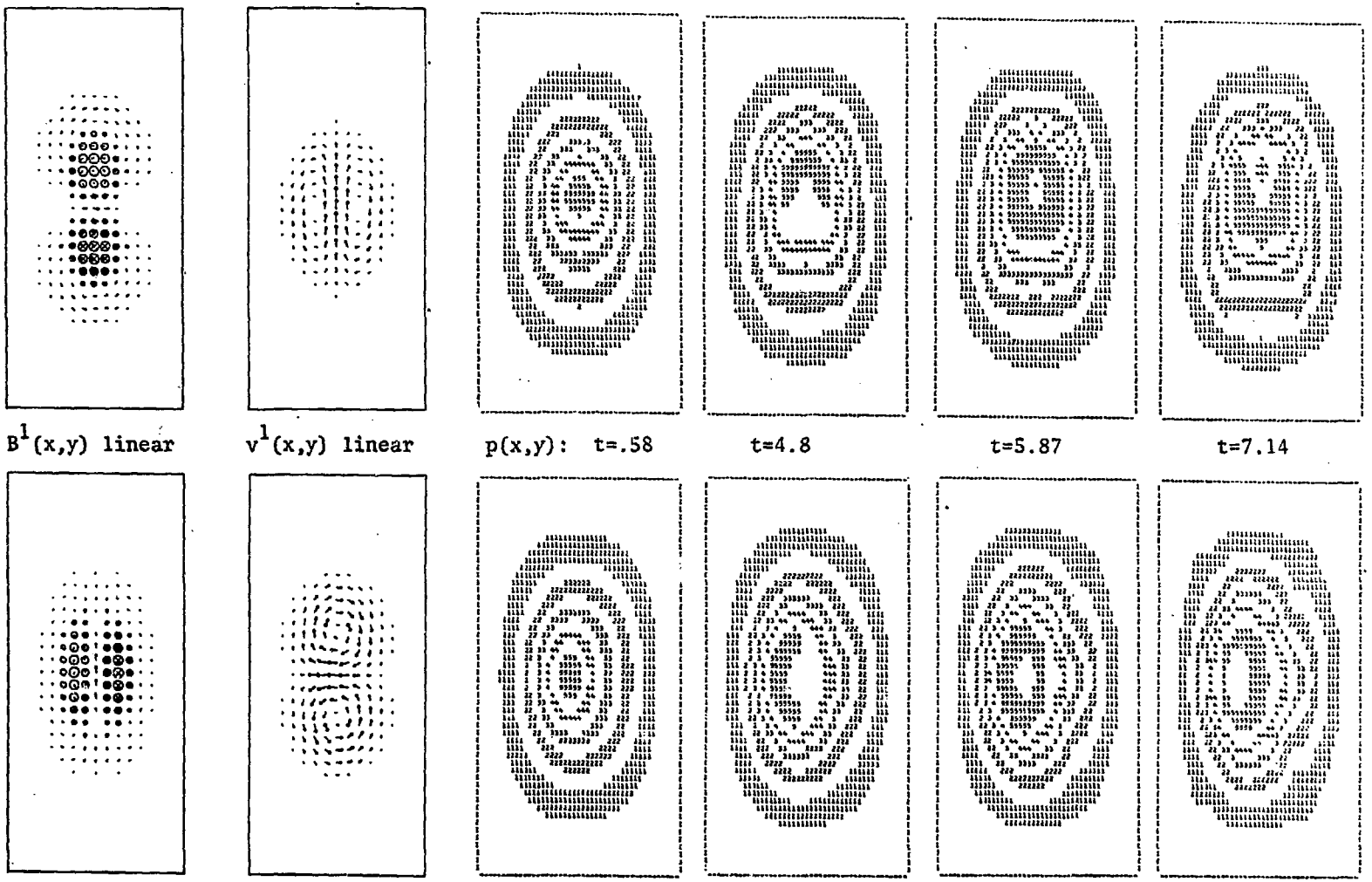

Fig. 1. Nonlinear development of m = 1 instability: q_c=.9, b/a=2, ka=1, γ=.228. Run #52

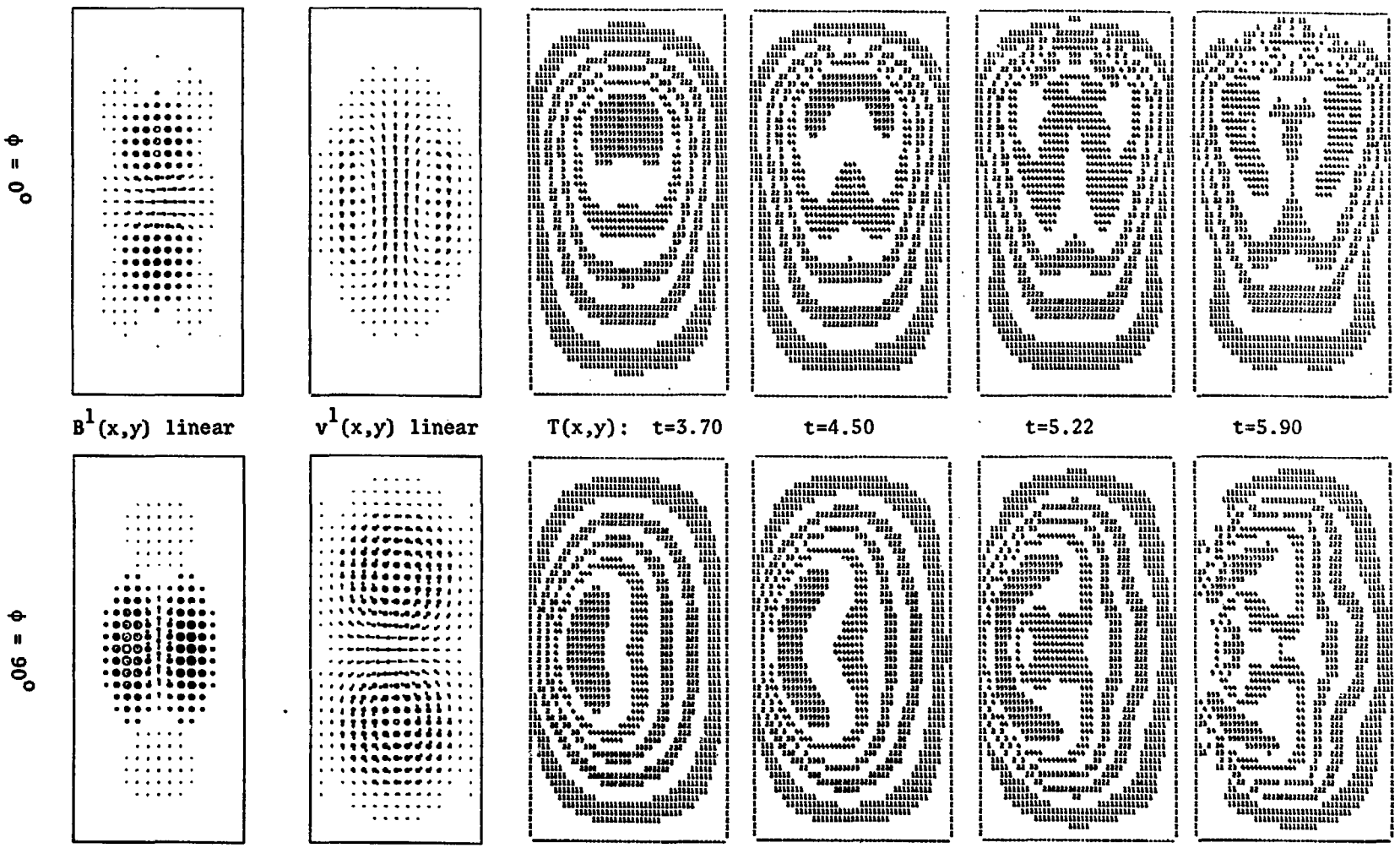

Fig. 2. Nonlinear development of m = 1 instability: q_c=.6, b/a=2, ka=1, γ=.52. Run #54