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"STUDY OF ALPHA PHYSICS RELATED TO ITER PROJECT"

Progress Report

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STUDY OF ALPHA PARTICLE PHYSICS RELATED TO ITER PROJECT

Progress Report - August, 1994

I. Introduction

A critical issue in the controlled fusion program is the understanding of alpha particle confinement in an ignited tokamak plasma. The standard ignition scenario in a burning plasma is that alpha particles are born at 3.5 Mev, and heat the background plasma as they transfer this energy by electron drag during the time they slow down. However, several experiments have already demonstrated that if Alfvén waves are excited by the presence of fast particles, the wave fields can cause rapid particle loss through radial diffusion. If such processes arise in a reactor, the entire methodology of planning what ignition conditions should be like, needs to be strongly modified. Hence, the understanding of the Alfvén-alpha particle interaction is one of the most significant issues that can be addressed as the plasma physics community prepares for an ITER experiment to demonstrate controlled fusion conditions. Should Alfvén wave excitations be present in a burning reactor, an appropriate method of analysis needs to be developed. The past year, the research team, working with the P.I. of this contract, has developed a method of analysis that should be appropriate for this problem. During the past year a numerical tool was successfully developed for a model problem that contains physics properties similar to the Alfvén-alpha particle problem. Work is now in progress for simulating the more realistic Alfvén-alpha particle problem.

II. Past Work

During the past several years, significant new understanding has emerged in describing the Alfvén-alpha particle interaction. The new areas of understanding include linear and nonlinear theory. In linear theory, the structure of the linear eigenmode, the linear instability drive, and damping needed to be understood. Many of the significant papers in this area were authored by the P.I. of this contract and his collaborators. For example, one work pointed out the importance of finite energetic orbit effects which gave a new scaling to the alpha particle drive that was significantly reduced from previous estimates in the literature.

The results of the linear theory indicate that the excitation of alpha particle driven Alfvén instabilities may give a weak instability spectrum. The question then arises of how to describe the nonlinear interaction. In this problem, the P.I. of this contract and Boris Breizman have pioneered in a new way to analyze the nonlinear problem. The method can be summarized as follows:

The classically expected alpha particle distribution in an ignited tokamak arises because a steady source is present which gives rise to equilibrium through the balance of classical transport processes, such as electron drag and pitch angle scattering of the alpha particles. For sufficiently weak instability, the spectrum of eigenmodes that can be excited only affects a limited region of the alpha particle phase space. As a result, waves can saturate at a relatively low level by a wave trapping process without an appreciable anomalous loss of alpha particle energy. Even for this case, bursts of instability radiation is expected. The bursts are separated by the time for classical processes to reconstitute an unstable distribution. We start from a saturated stabilized state, where the distribution of resonant particles are in a flattened plateau. Classical processes then cause the distribution to build up to a shape close to the structure predicted by classical transport theory. Then a pulse of radiation develops and the resonant particle distribution flattens locally in phase space, thereby eliminating the instability drive, and background dissipation mechanisms can then damp away the wave. This then again allows the reformation of the distribution predicted by classical theory. In this scenario, only resonant particles are affected, so that the overall shape of the distribution function remains as predicted by classical transport theory. Hence, the deposition of energy of alpha particles to the background plasma, is nearly the same, as predicted by classical transport.

A much more dramatic scenario, that can be a cause for concern, emerges if the resonant width of excited particles (the width can be predicted from linear theory) from different orbit resonances and various excited eigenmodes, overlap. Then a "phase space explosion" is predicted, similar to laser action. As there are then no dynamical barriers that prevent the distribution from flattening in phase space, the alpha particles release all their free energy in the form of Alfvén waves, which further diffuse the particles. This rapid phase space diffusion is in fact real space diffusion for the Alfvén wave-alpha particle interaction. Depending on the tokamak size, a significant fraction of alpha particles will either be lost to the walls, or spread further out to the plasma periphery. In any event, it is important to understand when conditions for this type of phase-space explosion is established. Such explosions take the form of a pulsation phenomena. We believe such an explosive-cyclic scenarios qualitatively explains observed experimental phenomena.

III. Accomplishments in Fiscal Year 1993-94.

The scenario that has been developed seems believable and applicable to many systems, including the plasma wave problem where there is a bump-on-tail distribution supported by a steady source, which causes instability. This past year we verified our

ideas in a quantitative manner with calculations on the bump-on-tail model. The following has been accomplished:

(1) A self-consistent nonlinear map model for the evolution of the distribution of resonant particles and waves was developed. A report with preliminary results is included in Appendix A. The code has the novel feature that it operates with sources and sinks so that continuous operation is possible and pulsations or steady noise can be exhibited. The code was also able to exhibit an explosive phase, that occurs when mode overlap causes a global relaxation of the particle distribution function (see Figures 1,2).

(2) A reformulation of the map model problem so that the Alfvén-alpha particle interaction can be applied to realistic tokamak geometry. It is shown that the basic mathematical structure still persists as in the bump-on-tail problem, but now there are more degrees of freedom that can evolve.

The results of these accomplishments will be presented at the 1994 IAEA Conference and the 1994 APS Conference. The abstracts of these submittals are in Appendix B, C and D. Papers are presently in preparation for publication.

IV. Work in 1994-95

At present a code is being developed to describe the Alfvén-alpha particle problem. The first runs will be for a beam simulation with zero perpendicular energy and in the relatively good approximation that the particle energy is conserved during the particle wave interaction. After completing this phase of the work, the code will be extended in dimensions to allow the energy to charge and for the particles to have arbitrary perpendicular energy. An important extension that we will try to address is to introduce classical drag and diffusion processes. By including these processes we would have in place the complete dynamics (both classical diffusion and wave-particle diffusion) for the evolution of an alpha particle distribution in an igniting plasma.

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Fig. 1. Time evolution of the total wave energy for the nonlinear bursts of two overlapped modes

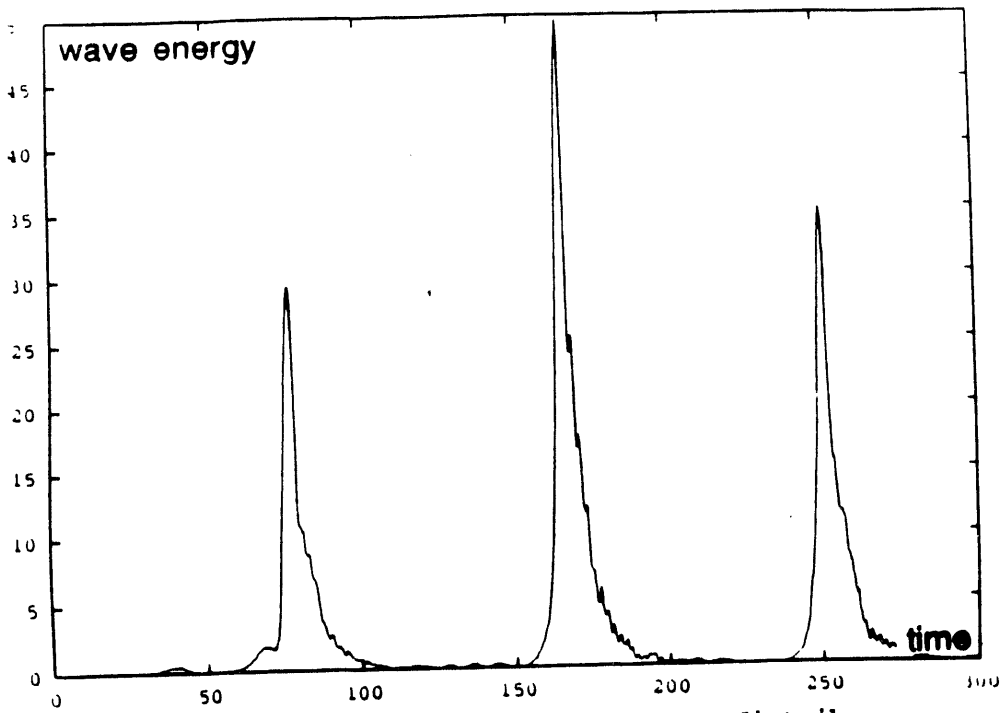
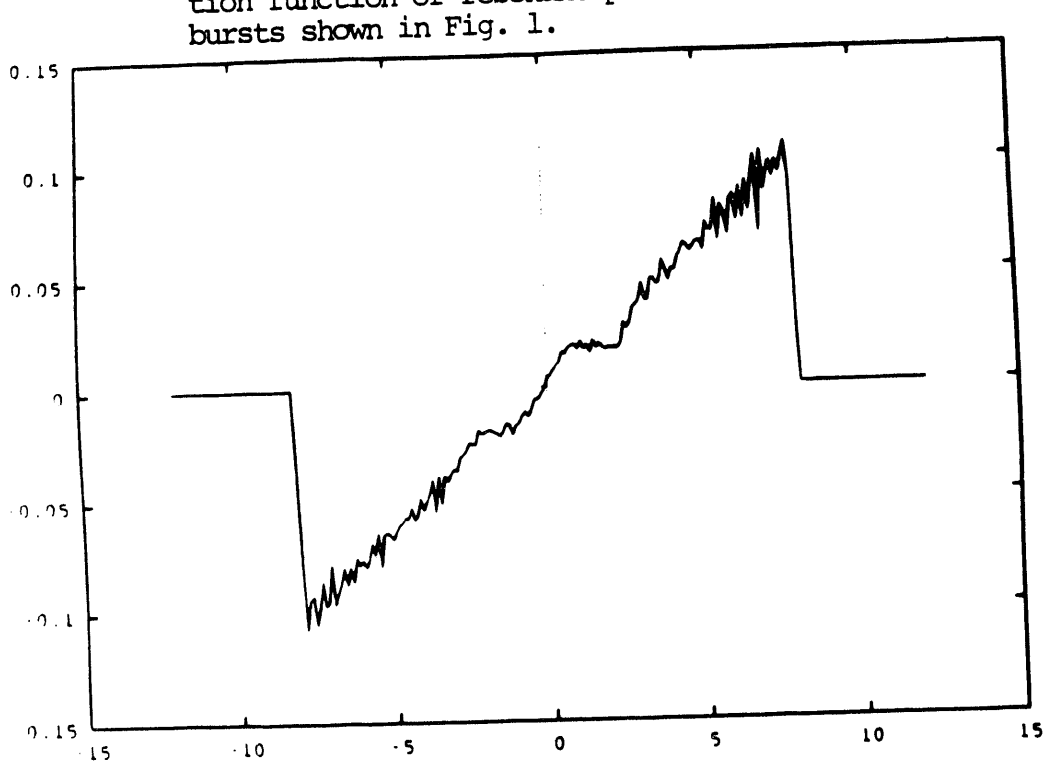


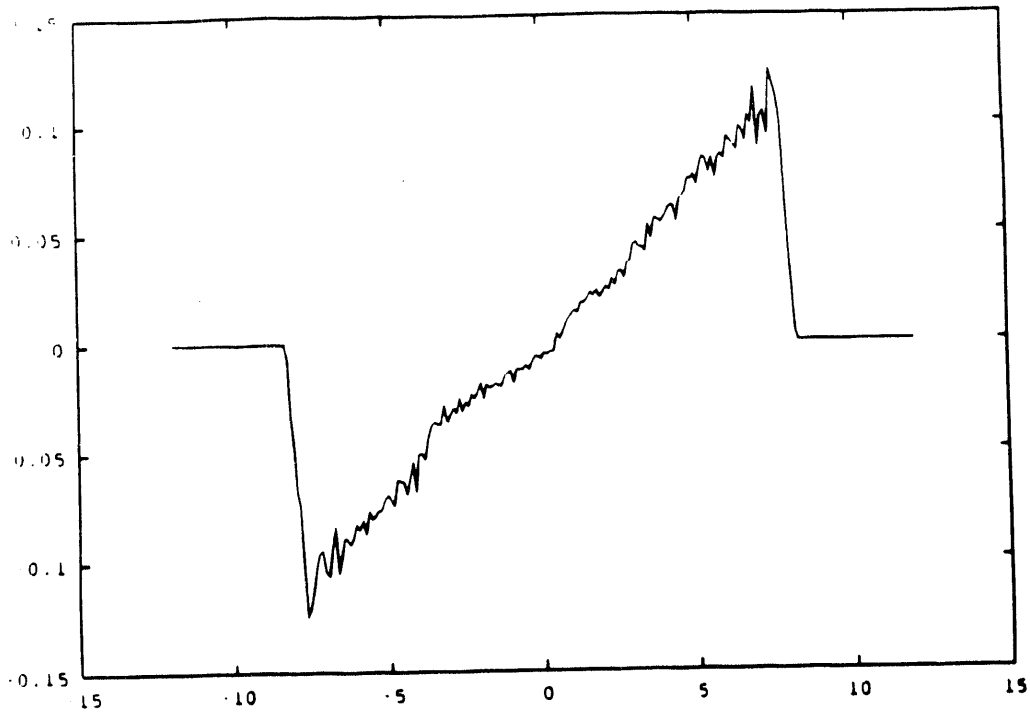
Fig. 2. A set of snapshots of the distribution function of resonant particles for the bursts shown in Fig. 1.

a)



a) An early stage of the first burst when the two modes have not yet overlapped (note the local plateaus near the resonances with each mode)

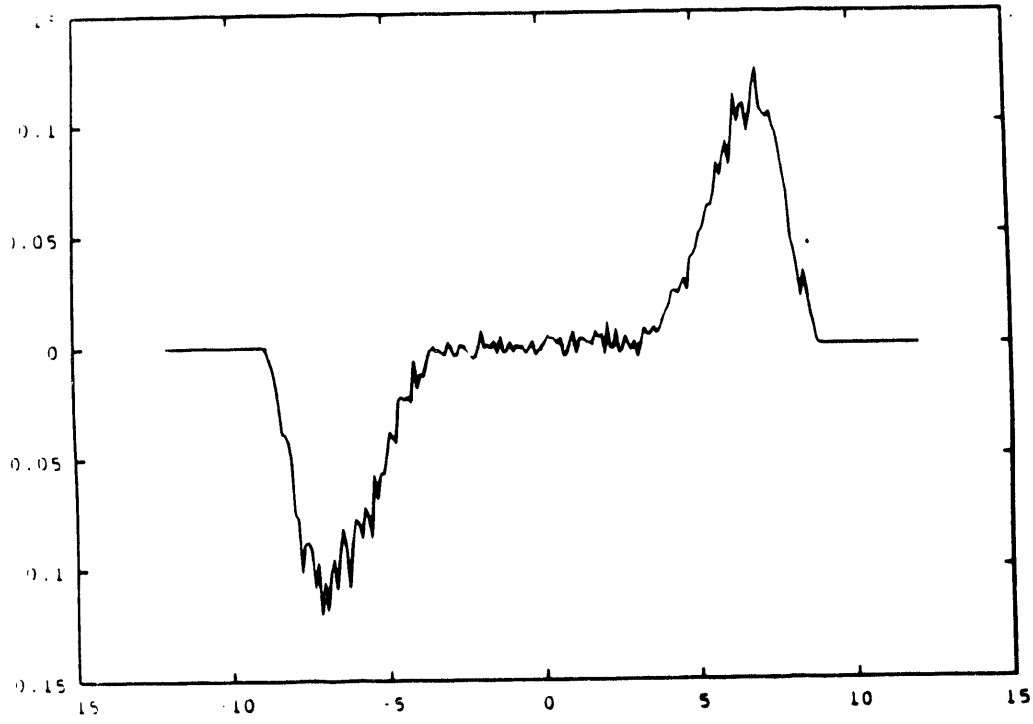
b)



Particle distribution
t = 70

b) merging of the two resonant regions during the burst

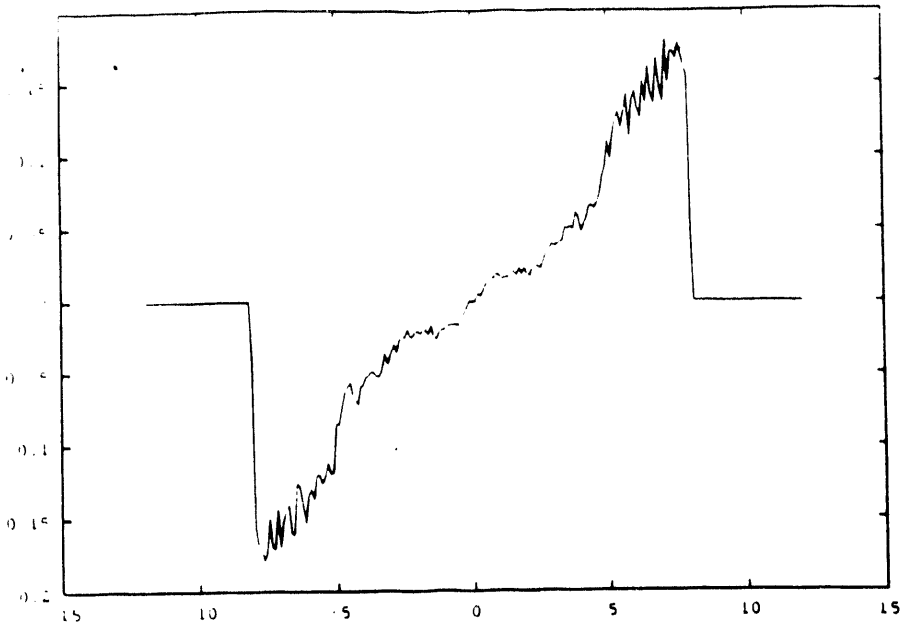
c)



Particle distribution
t = 80

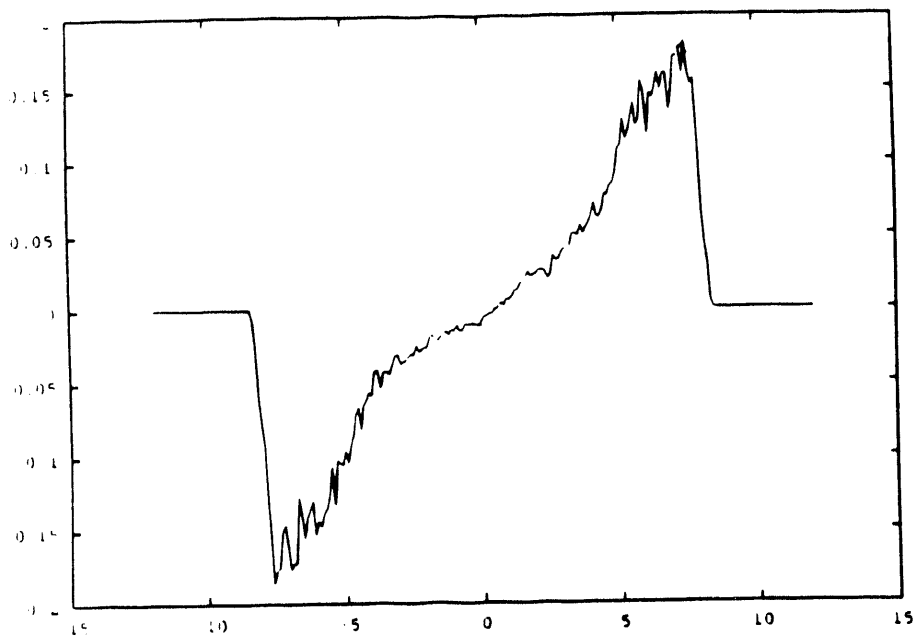
c) globally flattened distribution immediately after the burst

d)



Particle distribution
t = 150

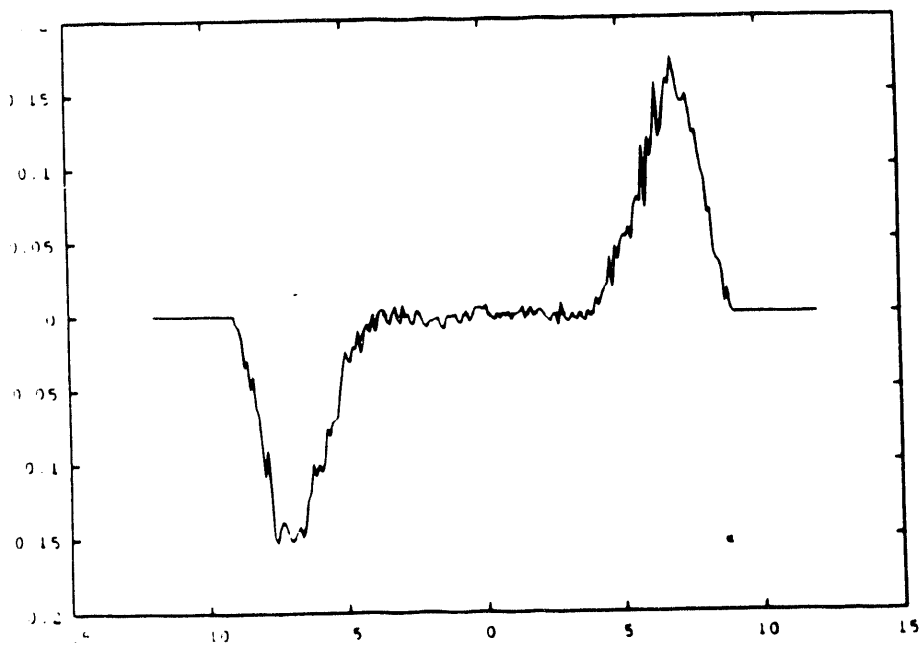
e)



Particle distribution
t = 160

d,e) reconstitution of the distribution function between the first and the second burst

f)



Particle distribution
t = 170

f) globally flattened distribution after the second burst

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