GA–A26669

RESPONSE OF A RESISTIVE AND ROTATING TOKAMAK TO EXTERNAL MAGNETIC PERTURBATIONS BELOW THE ALFVÉNIC FREQUENCY

by

M.S. CHU, L.L. LAO, M.J. SCHAFFER, T.E. EVANS, E.J. STRAIT,
M.J. LANCTOT, H. REIMERDES and Y. LIU

FEBRUARY 2011

GENERAL ATOMICS

DISCLAIMER

GA–A26669

RESPONSE OF A RESISTIVE AND ROTATING TOKAMAK TO EXTERNAL MAGNETIC PERTURBATIONS BELOW THE ALFVÉNIC FREQUENCY

by
M.S. CHU, L.L. LAO, M.J. SCHAFFER, T.E. EVANS, E.J. STRAIT,
M.J. LANCTOT,* H. REIMERDES* and Y. LIU†

This is a preprint of a paper to be presented at the 23rd IAEA Fusion Energy Conference, October 11–16, 2010 in Daejon, Republic of Korea and to be published in Proceedings.

*Columbia University, New York, New York, USA
†Dalian University of Technology, Dalian, LianoNing, China

Work supported in part by
the U.S. Department of Energy
under DE-FG03-95ER54309, DE-FC02-04ER54698,
and DE-FG03-99ER54541

GENERAL ATOMICS ATOMICS PROJECT 03726
FEBRUARY 2011

In this work, we show that plasma excitation at greatly disparate frequencies [toroidal Alfvén eigenmode (TAE) to resistive wall mode (RWM)] can be studied in a single framework of minimizing the free energy of the tokamak together with the external coils. We show that taking into account the plasma intrinsic response — with the inclusion of plasma resistivity and rotation, the proper perturbed plasma state, in particular the magnetic field topology, can be obtained to resolve puzzles regarding plasma transport in perturbed plasmas.

External magnetic perturbations generated by current carrying coils were utilized for various purposes in the study of tokamak plasmas. At higher (Alfvén range) frequencies, it can excite various plasma waves; whereas at lower frequencies, it was utilized for the correction of error fields and/or for the feedback stabilization of various low frequency instabilities, including the RWM [1]. Recent experiments in DIII-D and JET have shown that these external magnetic perturbations can modify plasma properties at the edge and stabilize the edge localized modes (ELMs) [2]. One of the intriguing aspects of this stabilization is that it depends critically not only on the configuration of the external magnetic coils (and perturbations), but also on the plasma state to which the magnetic perturbation is applied. To extrapolate these effects reliably to future devices, such as ITER, we need to have a comprehensive understanding of the underlying physical phenomenon and also a simulation capability for the combined system of plasma and external coils.

Minimization of the free energy of the plasma and the external coils is achieved for the tokamak configuration by directly solving the Euler equations using the MARS-F [3] code. In the MARS-F formulation, the plasma toroidal flow, resistivity and/or various other non-ideal kinetic effects and arbitrary external coil geometry were taken into account. The total response and especially the intrinsic plasma response (the total response excluding the vacuum response) has been found to depend quite critically on the toroidal flow and resistivity, especially for the lower range of frequencies. Previous systematic treatments neglected the intrinsic plasma response (plasma treated as a vacuum); and useful conclusions were obtained from the SURFMN-code [4]. A main conclusions from applying the SURFMN code to DIII-D results was that at conditions in which the ELM suppression was observed, outer ~10% plasma flux surfaces were found to be stochastic. It is viewed as a puzzle to the observation that the plasma edge remains in the H-mode with good confinement [5].

We proceed by first formulating the vacuum response independently by using an analytic method and test it against the numerical codes. Neglecting the plasma response, results from MARS-F are found to give excellent agreement with results from SURFMN and also that given by the analytic model. Next the plasma is tested for various resistivity and flow profiles and external coil configurations. First, we observe that intrinsic plasma response affects most significantly the components of the perturbations that have a resonance in the plasma. For an ideal-plasma, these resonant components are amplified inside of the resonances and as expected, completely suppressed at the mode singular surfaces. When plasma resistivity is included, this suppression (or shielding) becomes imperfect. However, with experimentally measured rotation profile, and with a wide range of plasma resistivity, the shielding remains substantial. This is shown in Fig. 1. The amplitudes of the resonant (m=10,n=3) harmonic of the perturbed normal magnetic field B_n for various levels of plasma resistivity, with magnetic Reynolds numbers ranging between S=10^6 to 10^8) are compared with that of the ideal plasma (blue) and vacuum (red). We note that the plasma response is very much like ideal plasma and deviates substantially from the vacuum. Two features are prominent here, one is the peak of the response at ψ=0.8 and the other is the suppression of the response outside of this amplification peak.

In comparison to the vacuum response the size of the magnetic island, which is proportional to $\sqrt{B_n}$ at the q=10/3 surface, is much reduced and it is not expected to lead to field line stochasticity in the outer ~10% of the flux surface. Similar results were found for different plasma shapes with various plasma elongation and triangularity. The stochastic region exists, but it is limited to the outer ~2% of the flux surfaces, which is consistent with the observation of only very minor modification to the plasma transport.

At higher frequencies, which are relevant for MHD modes such as TAE, BAE and RSAE, we found that the frequencies of plasma response with large kinetic energy δK are independent of the excitation geometry of the external coils, but the amplitude could be very different. This is shown in Fig. 2. The width in frequency of these response peaks can be related to the continuum damping [6]. It can also be obtained by using the method of adding plasma resistivity [7].

We conclude that the present formulation and results can be extended to study the perturbation of plasma by external magnetic perturbations in future devices, such as ITER.

This work was supported in part by the US DOE under DE-FG03-95ER54309 and DE-FG02-89ER53296.

[1] M.S. Chu and M. Okabayashi, "Stabilization of the External Kink and the Resistive Wall Mode," submitted to Plasma Phys. Control. Fusion.
[2] T.E. Evans, *et al.*, Nucl. Fusion **45**, 595 (2005).
[3] Y.Q. Liu, *et al.*, Phys. Plasmas **7**, 3681 (2000).
[4] M.J. Schaffer, *et al.*, Nucl. Fusion **48**, 024004 (2008).
[5] I. Joseph, *et al.*, J. Nucl. Mater. **363-365**, 591 (2007).
[6] L. Vilalrd, *et al.*, Compt. Phys. Reports **4**, 93 (1986).
[7] W. Kerner, *et al.*, J. Compt. Phys. **142**, 271 (1996).

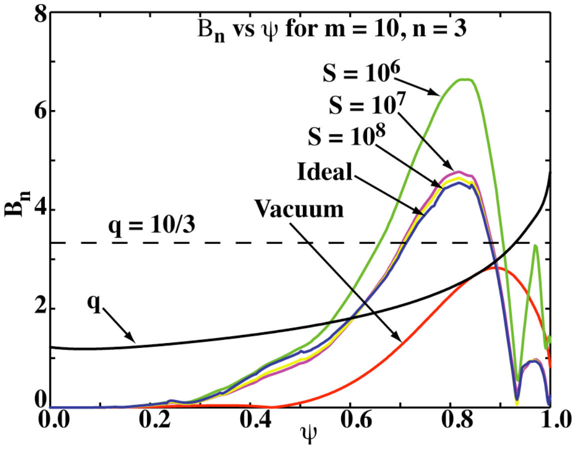

Fig. 1. Comparison of the amplitudes of the resonant (m=10,n=3) harmonic of the response of the plasma to externally induced perturbations as a function of plasma resistivity. The black curve is the q profile. The solid colored curves are for m=10. The red (blue) curve is for vacuum (ideal)-plasma. The (green, magenta, yellow) curves are for plasma Reynolds number (10^6, 10^7, 10^8). A DIII-D plasma with a realistic rotation profile is used and the coil configuration is that of the I-coils with up-down symmetric connection. It is seen that the plasma response is very similar to that of an ideal-plasma and deviates substantially from the vacuum.

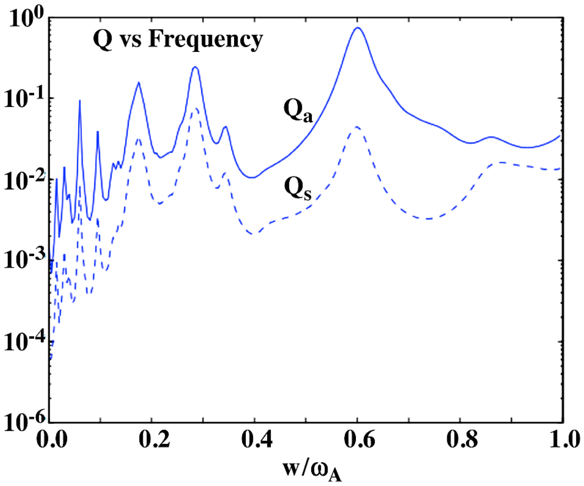

Fig. 2. Ratio of the total kinetic energy in the plasma to that of the Poynting flux at the antenna coils as a function of the frequency (in units of Alfvén) for a DIII-D plasma using the I-coils for excitation. The curves are the up-down asymmetric (symmetric) I-coil connections. It is seen that the excitation spectrum peak and width are independent of the antenna configuration, but the efficiency of excitation is quite different.