Active Measurement of Resistive Wall Mode Stability in Rotating High Beta Plasmas[*]

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We present an absolute measurement of the damping rate and the rotation frequency of the stable resistive wall mode (RWM) in rapidly rotating DIII-D plasmas above the conventional, no-wall kink-ballooning stability limit. In these plasmas toroidal plasma rotation in the order of a few percent of the Alfvén velocity v_A. is sufficient to stabilize the n=1 RWM [1]. The stability of these high-β plasmas has been probed by extending the technique of active MHD spectroscopy, previously used at frequencies above 10 kHz [2], to frequencies of a few tens of Hertz. The comparison of the obtained measurements with numerical calculations directly tests the proposed dissipation mechanisms, which are required for rotational stabilization of the RWM.

The mechanism of RWM stabilization by plasma rotation, caused by some dissipation in the plasma [3], has been under debate for the last decade. The stabilization of the RWM can extend the operating regime of tokamaks beyond the conventional no-wall ideal MHD β-limit up to the ideal wall limit and hence allow for smaller and more efficient fusion reactors. Operation above $\beta_{\text{no-wall}}$ is particularly important in advanced tokamak scenarios, which rely on a large fraction of pressure driven current. A reliable extrapolation of the stabilizing effect of plasma rotation to a future experiment such as ITER, however, requires a complete understanding of the underlying dissipative process. The measurements presented here allow for a quantitative test of the predicted stabilization mechanisms.

Such a test can be made by "passively" measuring the critical rotation required for rotational stabilization v_{crit}. It is found that v_{crit} is proportional to the Alfvén velocity with v_{crit} at the q=2 surface being 2% of the local v_A. The measurement of v_{crit} for values of β ranging from the no-wall up to the ideal wall limit has revealed only a weak β-dependence.

"Active" measurements (Fig. 1) probe the stability even before the mode becomes unstable and can, thereby, reveal more information about the magnitude of the damping and the natural rotation frequency of the mode. In the DIII-D experiments, two sets of non-

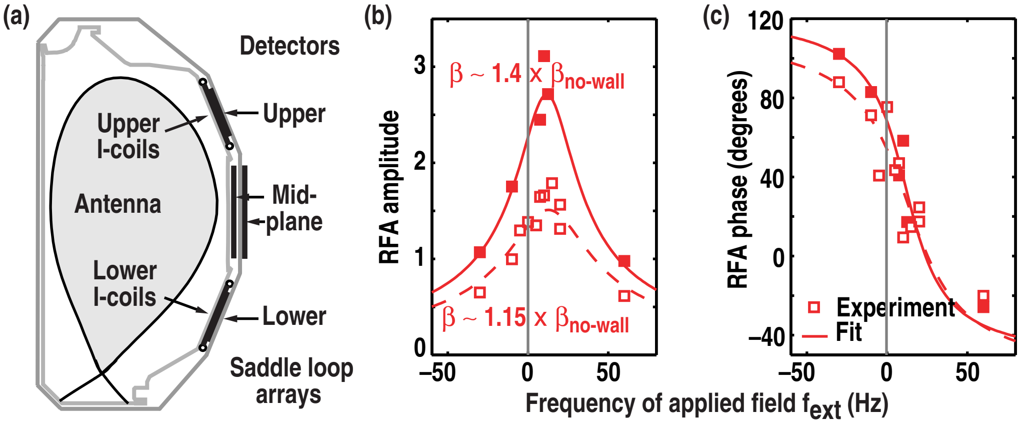

Fig. 1. Active MHD spectroscopy in DIII-D. (a): Location of the antenna and several detector arrays. RFA amplitude (b) and phase (c) for various applied frequencies at two values of beta.

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[*] Work supported by U.S. Department of Energy under DE-FG02-89ER53297, DE-AC02-76CH03073, and DE-FC02-04ER54698.

axisymmetric coils are used as antennas, Fig. 1(a). They can apply a pulsed or rotating magnetic field that has a large overlap with the RWM structure. The plasma response to the externally applied field is detected with several arrays of saddle loops measuring the perturbed radial magnetic field, Fig. 1(a). In the presence of a weakly damped mode, such as the RWM in a rapidly rotating plasma at high β, the plasma amplifies the resonant component of the applied field, a phenomenon referred to as resonant field amplification (RFA) [4]. In a single mode model the amplitude of the resonant field amplification A_{RFA}, which is defined as the ratio of plasma response and vacuum field, peaks when the externally applied frequency f_{ext} matches the rotation frequency of the mode. The RFA spectra, measured at two values of β, can be fitted to the single mode model showing that the model is applicable, Fig. 1(a,b). The fit parameter then yields an absolute measurement of the (negative) growth rate and rotation frequency of the RWM, Fig. 2. The fit also yields a geometrical coupling parameter, which depends on the resonant component of the applied field. Once the coupling parameter is known, the measurement of the RFA at a single frequency is sufficient to determine the RWM stability allowing for a continuous measurement of ideal MHD stability. An example of such a measurement using a low amplitude externally applied field with a rotation frequency of 20 Hz during a discharge, where β was increased up to an RWM onset, is also shown in Fig. 2. This continuous measurement looks promising as a real-time indication of the approach to the stability limit.

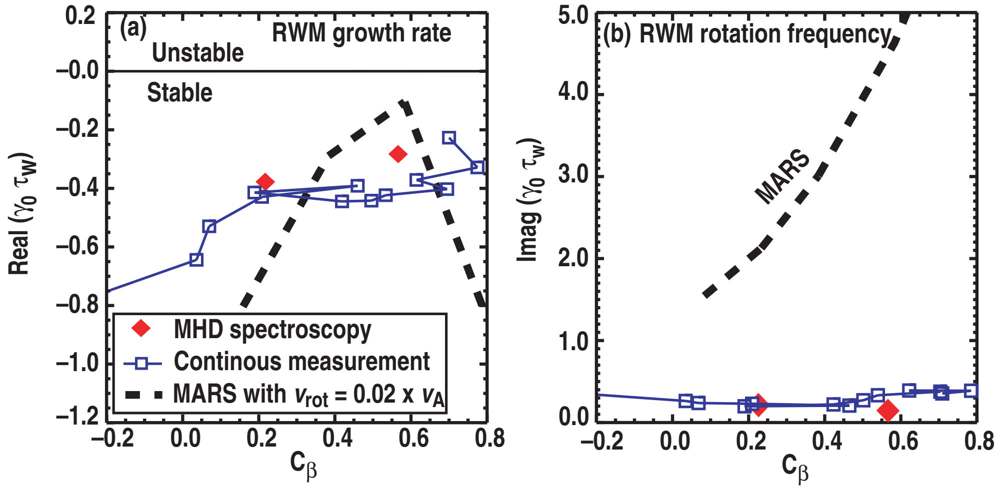

Fig. 2. Comparison of the measured growth rate (a) and rotation frequency (b) derived from the fit of the spectrum (diamonds) and from a continuous 20 Hz wave (squares) with MARS predictions using the sound wave damping model (dashed line).

The measured RWM damping rates and rotation frequencies can now be compared to predictions for dissipation models such as sound wave dissipation or kinetic damping using the MARS code [5]. A preliminary comparison using a flat plasma rotation profile and a generic equilibrium using the sound wave dissipation model [3] has been carried out. To compare the RWM growth rates, the gain in beta between the no-wall and ideal wall stability limit $C_\beta = (\beta - \beta_{\text{no-wall}})/(\beta_{\text{ideal wall}} - \beta_{\text{no-wall}})$ is used as the stability parameter. While the observed damping rate is in qualitative agreement with the predicted damping rate for a plasma rotation of 2% of the Alfvén velocity, Fig. 2(a), the observed natural rotation frequency is an order of magnitude lower than the predictions, Fig. 2(b). The spectroscopy results clearly indicate that further theoretical and experimental work is needed before results can be extrapolated with confidence to future experiments.

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