SUMMARY OF RECENT STUDIES OF BEAM-DRIVEN BAE AND CHIRPING MODES IN DIII-D

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ABSTRACT. In high beta DIII-D plasmas with intense neutral beam injection, beta induced Alfvén eigen-modes (BAE modes) are observed. These instabilities cause concentrated losses of >50% of the fast ions and thus are of concern for future devices. The authors have now observed BAE modes and resultant fast ion loss in full field (2.0 T) discharges where the ratio of parallel velocity to Alfvén speed is \( v_{II}/v_A \approx 0.3 \). In a few discharges, they have also observed a new instability, a ‘chirping’ mode. These modes have frequencies between 50 and 200 kHz that ‘whistle’ down a factor of two in a single 2 ms burst. They occur in plasmas with relatively large values of fast ion beta \((\beta_f) \gtrsim 1\%\), Alfvén speed \(v_{II}/v_A < 0.5\) and plasma rotation \(f_{rot} > 20\) kHz. In contrast to the usual Alfvén modes, which are fluid modes of the background plasma, the chirping instabilities seem to be beam modes that are nearly stationary in the plasma frame.

Collective instabilities driven by energetic alphas may cause anomalous alpha transport, which may degrade the plasma performance or damage internal vacuum vessel hardware in a reactor. In DIII-D, deuterium neutral beam populations are used to simulate alpha particles. In these simulation experiments, the Alfvén gap structure and the ratio of fast ion to Alfvén speed, \(v_{II}/v_A\), are comparable to those anticipated in tokamak reactors, but the velocity distribution of the beam ions is anisotropic (near tangential injection in the direction of the plasma current is employed) and the ratio of fast ion gyroradius to plasma minor radius, \(\rho_f/a\), is several times larger than anticipated in ITER.

By the time of the third IAEA technical meeting on alpha particles, both TAE [1] and BAE [2] modes had been observed in DIII-D during intense neutral beam injection. Following the meeting, papers describing the real frequency [3], stability properties [4], anomalous transport [5] and bursting behaviour [6] of TAE modes appeared. In recent work, a new ‘chirping’ instability was observed, and BAE modes degraded plasma performance in full field \((B_T = 2.0\) T\), high poloidal beta

FIG. 1. Relationship of discharges with TAE or BAE activity (through the 1992 campaign) [4] to the 2.0 T discharge with BAE activity (shot 82956) and to the discharges with chirping modes. The ordinate represents the classically estimated, volume averaged beam ion beta \((\beta_f)\). (The actual value may be reduced by fast ion losses.) The abscissa represents the ratio of the parallel velocity of full energy beam ions that ionize on axis \(v_{II}\) to the Alfvén speed \(v_A\) (evaluated using \(B_T\) and \(n_e\)). The dotted lines demarcate the approximate thresholds in \((\beta_f)\) and \(v_{II}/v_A\) for strong Alfvén activity in DIII-D.
plasmas. This paper briefly summarizes these recent observations. More complete descriptions are currently being prepared [7–9].

Large values of beam beta are needed to drive these instabilities. In Fig. 1, the values of volume averaged beam beta \( \langle \beta_p \rangle \) and \( \nu_l/\nu_A \) for some of the recent observations are compared with earlier TAE and BAE results. Much of the recent work is at higher values of toroidal field (lower values of \( \nu_l/\nu_A \)). Although only one new BAE datum is shown in Fig. 1, BAE modes are found in hundreds of discharges with \( \langle \beta_p \rangle \gtrsim 1\% \) for a wide range of values of \( \nu_l/\nu_A \) [9]. In contrast, the chirping modes have only been observed in six discharges, all with \( \nu_l/\nu_A \lesssim 0.5 \).

BAE modes cause loss of \( \gtrsim 50\% \) of the beam power both in low field plasmas where \( \nu_l/\nu_A \sim 1 \) [5, 10] and in high field plasmas where \( \nu_l/\nu_A \simeq 0.3 \) [8]. Chirping modes are also associated with fast ion loss [7].

Figure 2 shows the frequency spectrum measured by magnetic probes in a discharge with \( B_T = 2.0 \) T. Above 80 kHz, the spectrum is characterized by a set of peaks associated with ascending values of toroidal mode number \( n \). The qualitative features of the spectrum resemble the TAE [3] and BAE [2] spectra observed in low field discharges \( (B_T \leq 1.4) \). The separation of the peaks is associated with the Doppler shift in these toroidally rotating plasmas [3]. The largest peak corresponds to \( n = 4 \), which is also characteristic of low field discharges [4].

Previously, it was found that the frequency of BAE modes scales approximately linearly with the Alfvén speed \( \nu_A \) [2]. The Doppler corrected BAE frequency in the 2.0 T discharge agrees well with the previous scaling (Fig. 3), further confirming that these instabilities are Alfvén modes.

Alfvén modes in DIII-D typically occur in bursts [6]. Within a single burst, any variation of the mode...
frequency is essentially undetectable ($\lesssim 0.5$ kHz). On successive bursts, the mode frequency typically varies a few kHz. In contrast, for chirping modes, the frequency typically varies a factor of two within a single burst. Figure 4 shows the frequency spectrum for a chirping mode. The broad spectrum is caused by the rapid temporal variation of the frequency during the burst [7]. The toroidal mode number ($n = 3$, in this case) remains constant throughout the burst, however.

The chirping modes occur in plasmas with relatively high values of toroidal rotation ($f_{\text{rot}} > 20$ kHz) [7]. Apparently, the large value of $f_{\text{rot}}$ accommodates a mode that is stationary in the plasma frame ($f_{\text{plasma}} \approx f_{\text{lab}} - n f_{\text{rot}} \approx 0$), yet can still resonate with the circulating beam ion population ($f_{\text{lab}} \approx n f_{\text{rot}} \sim f_{\text{circ}}$). These chirping modes seem to be a type of beam mode in which the plasma rotation plays an important role [7].

In summary, beam driven, intermediate $n$ instabilities with laboratory frequencies of $O(100$ kHz) are observed in DIII-D: the BAE and a chirping instability. Alpha driven chirping modes are not anticipated in a reactor, but their observation helps clarify the distinction [11] between beam modes and fluid modes. On the other hand, alpha driven BAE modes are potentially dangerous in future devices, particularly in tokamak reactors that operate at large values of poloidal beta.

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REFERENCES


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