Observation of Reversed Shear Alfvén Eigenmodes between Sawtooth Crashes in the Alcator C-Mod Tokamak

E. M. Edlund,[1] M. Porkolab,[1] G. J. Kramer,[2] L. Lin,[1] Y. Lin,[1] and S. J. Wukitch[1]

[1]*MIT Plasma Science and Fusion Center, Cambridge, Massachusetts 02139, USA*
[2]*Princeton Plasma Physics Laboratory, Princeton, New Jersey 08543, USA*

(Received 30 May 2008; published 22 April 2009)

Groups of frequency chirping modes observed between sawtooth crashes in the Alcator C-Mod tokamak are interpreted as reversed shear Alfvén eigenmodes near the $q = 1$ surface. These modes indicate that a reversed shear q profile is generated during the relaxation phase of the sawtooth cycle. Two important parameters, $q_{\rm min}$ and its radial position, are deduced from comparisons of measured density fluctuations with calculations from the ideal MHD code NOVA. These studies provide valuable constraints for further modeling of the sawtooth cycle.

DOI: 10.1103/PhysRevLett.102.165003 PACS numbers: 52.35.Bj, 52.65.Kj, 52.55.Fa

The sawtooth cycle has long been recognized as a robust feature of tokamak plasmas [1]. The cycle is composed of an abrupt crash in the central electron temperature and a relaxation, or reheat, phase (see Fig. 1, $t \geq 0.25$ s). The sawtooth crash is a process whereby the magnetic field lines interior to the $q = 1$ surface (where $q = rB_\phi/R_0B_\theta$ is the magnetic safety factor, r is the minor radial coordinate, B_ϕ is the toroidal magnetic field, R_0 is the tokamak major radius, and B_θ is the poloidal magnetic field) reconnect to lines outside of the $q = 1$ surface. In this process the magnetic field "frozen-in" laws are broken leading to rapid radial transport wherein the temperature, density, and current profiles are flattened [2–4]. Following the cessation of magnetic reconnection, the plasma relaxation phase is characterized by a nearly linear increase in the central electron temperature and an inward diffusion of parallel current formerly displaced by the reconnection. Understanding the evolution of the current profile and its relation to sawtooth phenomena is important, especially for future burning plasma experiments such as ITER, where an accurate model of the physics of the crash event and the subsequent relaxation process is crucial for developing predictive capability for sawtooth control. In this Letter we report observations of frequency chirping Alfvénic modes excited during the sawtooth cycle in Alcator C-Mod tokamak plasmas, herein identified as reversed shear Alfvén eigenmodes (RSAEs, also Alfvén cascades) located near the $q = 1$ surface. RSAEs should be of great interest for future burning plasma experiments both for their use as a form of MHD spectroscopy and because Alfvénic modes may negatively impact the confinement of the energetic ions in the plasma core [5]. Importantly, the presence of RSAEs near the $q = 1$ surface is interpreted as evidence of a hollow current profile during the sawtooth cycle.

The phase contrast imaging (PCI) diagnostic [6], a type of internal reference beam interferometer, is an outstanding tool for the study of core localized Alfvénic activity. The output signal of the PCI system is a 1D image, decomposed into 32 elements of approximately 4.5 mm chord separation in the direction of the major radius, which is linearly proportional to the line integral of the electron density perturbations along the beam path. The reporting of $q = 1$ RSAEs in Alcator C-Mod, and also in JET [7,8] (see also [9]), is due to the availability of diagnostics sensitive to small perturbations in the plasma core. In a few Alcator C-Mod experiments the amplitude of the $q = 1$ RSAEs was large enough allow for mode number identification with the magnetic pickup (Mirnov) coils.

Typical plasma parameters in Alcator C-Mod ($R_0 = 0.68$ m, $a = 0.22$ m, $\kappa \leq 1.85$) in which these modes are seen are $B_\phi = 5.4$ T, $I_p = 600$–800 kA and $n_{e0} \lesssim 1.5 \times 10^{20}$ m^{-3}. Up to 5 MW of auxiliary heating is provided by ion-cyclotron resonance heating (ICRH) at the fundamen-

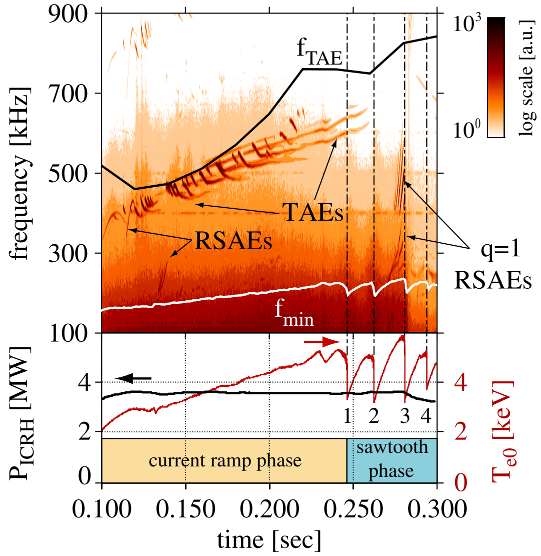

FIG. 1 (color online). PCI spectrogram showing the range of modes observed in the current-ramp and early sawtoothing phase. The numbers below the T_{e0} trace denote the sawtooth crash number relative to the beginning of the shot. $T_i/T_e = 0.8$ has been used for the calculation of $f_{\rm min}$.

© 2009 The American Physical Society