J. Plasma Fusion Res. SERIES, Vol. 8 (2009)

EXCITATION AND SUPPRESSION OF ALFVEN EIGENMODES (AEs) BY USING DED COILS

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(Received: 12 September 2008 / Accepted: 1 May 2009)

Alfven eigenmodes (AEs) excited by high energy particles are predicted to play an important role in the confinement of particles in nuclear fusion reactors. In order to study the stability of AEs and develop the method to suppress them, we excite AEs in TEXTOR tokamak plasma by using the dynamic ergodic diverter (DED) coils as an external antenna.

DED coils are wound inside the vacuum vessel at the high field side. The field modes of m/n=12/4, 6/2 and 3/1 can be excited by changing the coil configuration, where m and n are poloidal and toroidal mode numbers, respectively. An rf current of ≤ 5A with frequencies swept from 100kHz to 1MHz was applied on the DED coils. Coil impedance was measured as a function of frequency for Ohmic plasmas (Ip = 400 kA, Bt = 2.25 T, n_e~2x10^{19} m^{-3}). Wave magnetic fields were detected by the Mirnov coils installed around the torus. The effects of the ergodization of the edge magnetic fields on AEs were studied by superimposing a dc current on the DED coils. A reduction of AEs excited by the rf was observed by applying a small DED current (~0.5kA) which does not have notable effects on plasma parameters at the periphery.

Keywords: Alfven eigenmodes, TEXTOR, DED coils, ergodic field, TAE, impedance measurement

1. Introduction

Weakly damped Alfven eigenmodes excited by high energy ions such as alpha particles created by DT fusion reaction are recognized as one of important elements for the confinement of alpha particles themselves in the International Thermonuclear Experimental Reactor (ITER). It is thought that due to the interaction of AEs with energetic ions the modes become possibly unstable and the particle orbits are modified to enhance the loss and affect the ignition process in fusion reactors. Alfven eigenmode activities driven by resonant energetic particles produced by ion cyclotron heating (ICH) and neutral beam injection (NBI) have been studied in different tokamak experiments [1, 2]. Energetic ion losses and the resultant reduction of the neutron production accompanied with the appearance of toroidicity induced AEs have been observed [3]. Due to the driving terms of NBI and ICH, it is difficult to study damping and stability of the modes in passively excited AEs in such experiments. The active methods combining excitation by externally introduced antenna and coherent detection of magnetic fluctuation signals at the plasma edge and core has been developed in JET [4]. Here, we use DED coils in TEXTOR [5] as an antenna to excite AEs and aim to investigate not only their characteristics but also the effects of edge field ergodization on AEs.

2. DED antenna system and diagnostics

DED coils consist of 16 perturbation coils wound around the high field side of the torus (poloidal extension: 70^0) as shown in Fig.1. The coils generate the perturbation fields which have Fourier components having magnetic islands near the plasma edge. The perturbation fields are not only static but also rotatable in the helical direction (predominantly in the poloidal direction). The ac frequency of the fields goes up to 10 kHz, and the resulting poloidal rotation velocity can exceed that of the diamagnetic drift. A four-phase current up to 15 kA on the DED coils makes ergodic fields at the plasma surface. One or two pairs of DED coils are used as an antenna for

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the AEs excitation. The maximum rf frequency, current and voltage induced in the coils using the rf amplifier are 1MHz, 5A and 75V (zero to peak values), respectively. The coil set can be chosen to excite the perturbation fields of the poloidal and toroidal modes of m/n=12/4, 6/2 and 3/1 (the effective maximum poloidal mode numbers are 20, 10 and 5, respectively). Coil inductance is ~15 μH for m/n=3/1 mode at 100kHz. The magnetic perturbation field normalized by the total field $\delta B/B$ is estimated as ~5x10^{-6} for m/n=3/1 (rf current ~5A, r/a=0.9, q_a=3). In order to estimate the antenna loading for AEs excitation, coil current and voltage are measured by the Rogowski coil and the capacitive coupler, respectively (Fig. 2). The capacitive coupler picks up the voltage on the coil through a thin dielectric ceramic plate which also isolates the coupler from the high voltage on the coil. The small rf signal can be superimposed on the large dc DED current to study the effects of edge field ergodization on AEs. The excited AEs fields in the plasma are measured by the Mirnov coils located at several toroidal and poloidal directions.

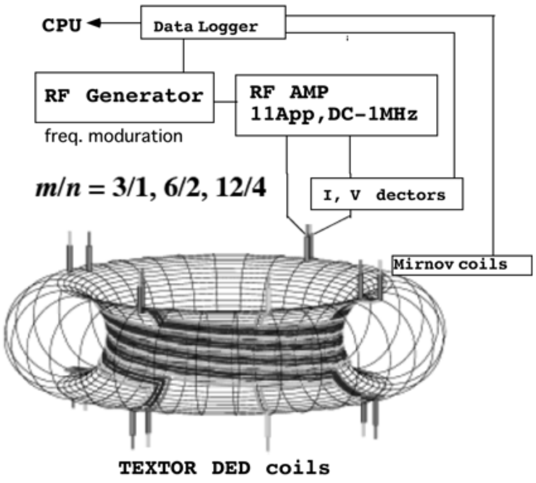

Fig. 1 DED coils and AEs antenna system

3. Coil impedance measurements for AEs-excitation

In Fig. 3 (a), examples of line averaged electron density n_e and plasma current I_P are shown for typical TEXTOR plasma discharge where toroidal field B_t is 2.4 T. The preliminary results shown here are obtained by using the DED of 3/1 operation mode. The rf current with the frequency swept from 100 to 1MHz in 1 sec is applied on the coils during the flat top period of the discharge (Fig. 3(a)). The frequency spectrum of voltage pick-up and current signals shows peaks at the exciter rf frequency and also its higher harmonics (Fig.3 (c)-(d)). Independent of plasma operations, several electrical noises appear on the voltage pick-up due to the high impedance detection system and the floating coil potential. When the plasma is produced, the real part of the coil impedance (expressed as a coil loading which is defined as a component with the same phase to the coil current) increases from the vacuum impedance and shows some peaks around

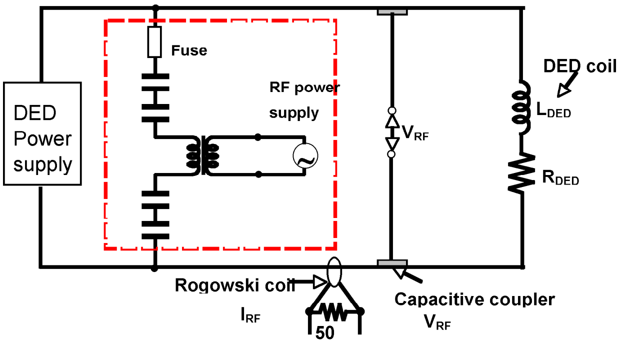

Fig. 2 Rf antenna circuit and impedance diagnostics

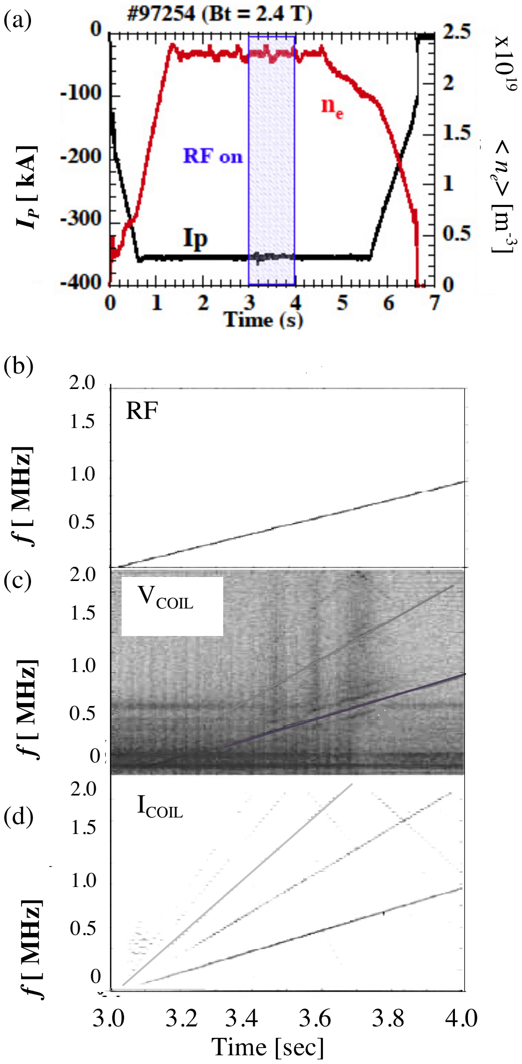

Fig. 3 (a) *Ip* and ne of TEXTOR shot. Frequency spectrum of rf exciter (b), coil voltage (c) and current (d) versus time, respectively.

200kHz and 400kHz (Fig. 4) which are consistent with those expected for AEs as shown in Sec. 4.

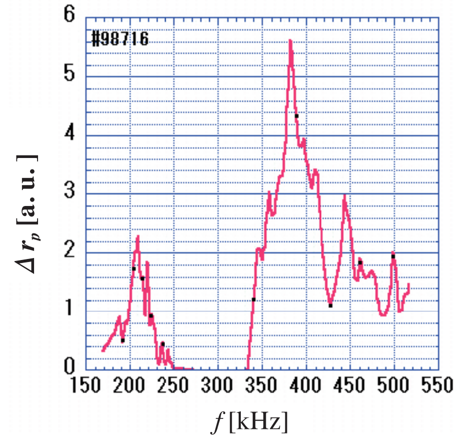

Fig. 4 Power spectrum of the change in the coil loading resistance from the vacuum. Bt=2.25T, $<n_e>$= 3.2×10^{19}m^{-3}, m/n=3/1 DED coil.

4. Suppression of AEs by DED ergodic fields

One of the basic features of DED coils with dc current operation in TEXTOR is to make ergodic magnetic fields at the plasma periphery and thus diffuse the localized heat loading on the limiter surface [6]. The DED coils for m/n=3/1 configuration contain higher harmonics fields of the poloidal modes. The shear Alfven continuum for n=1 modes as a function of minor radius are calculated using the code AE3D [7] (Fig. 5 (a)). TAE (toroidal Alfven eigenmode) modes around 200kHz and EAE (elliptic Alfven eigenmode) around 400kHz (due to the finite beta shift of the plasma) appear in the continuum gap frequencies in plasma periphery. When DED fields are produced, the magnetic field structures are modified. The Poincare′ section of the magnetic field lines in a flux coordinate (θ, ρ) for DED current I_{ded} of 1.5kA in m/n=3/1 operation is displayed in Fig. 5(b). The perturbation fields destroy the rational magnetic surfaces at q=m/n and create a chain of isolated islands. Increasing the DED current results in overlapping of those islands from the higher poloidal mode numbers m and ergodic field lines are formed in the plasma periphery [6]. In Fig.5(b), overlapping of the islands m/n=3/1 and 4/1, and the ergodic region around them, can be seen. When I_{ded} increases further, m/n=2/1 islands and ergodic region grow and finally the laminar region, having short connection length appears in the plasma edge region. Modification of the magnetic field structure by the perturbation fields is predominant in the region where the AEs are excited (shaded area in Fig. 5(a)). In order to see the influence of these magnetic perturbations on AEs, we superimposed a small amplitude of rf current on I_{ded} at the flat-top plasma density as shown in Fig. 6. The DC current is applied up to 7.5kA and the rf current is ~5A (the frequency is swept during 1 second from 100kHz to 1MHz). The coherent rf signals of coil current and voltage can be measured under this condition. Mirnov

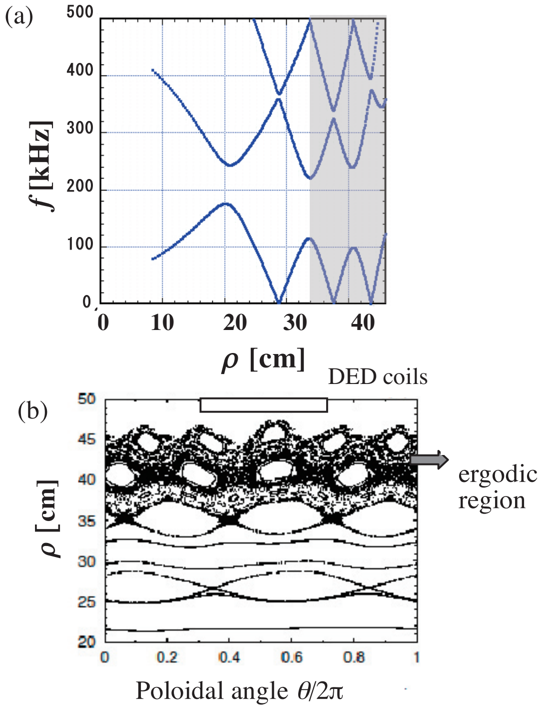

Fig 5. (a)Alfven resonance frequency versus radius ρ for n= 1 mode. Where B_T=2.25T, Ip=300kA, R=1.75m, a=0.46m, $n_e=n_{eo}(1-0.9r^2)$, $n_{e0}=3\times10^{19}$, $q=q(a)\rho^2/[1-(1-\rho^2)^{2.5}]$, $q(a)$=4.53, $j=j_o(1-\rho^2)^{1.5}$, β_P=1.2. [7]. (b) Poincare′ plot of toroidal field lines in the m/n=3/1 operational mode for the conditions; I_{ded}=1.5kA, B_t = 2.25 T, I_p = 300 kA and β_{pol}=0.3.

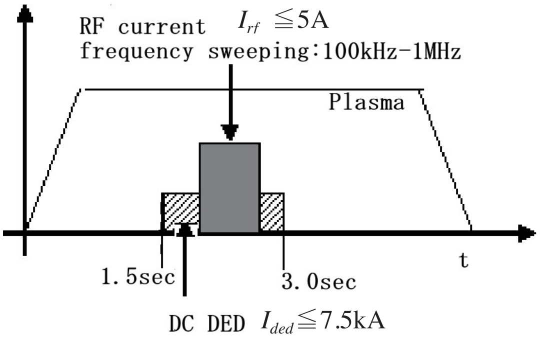

Fig 6 Time sequence of plasma discharge, exciter rf and DC current on DED coil.

coil placed almost 90 degrees away from the rf coil in poloidal direction detects the rf magnetic field perturbation during the plasma shot. An example of the power spectrum of Mirnov coil signal normalized by the rf coil current as a function of I_{ded} is shown in Fig. 7, where Ip=430 kA, Bt=2.25T and ne=2x10^{19}m^{-3}. The AEs (TAE and EAE modes) are excited when I_{ded}=0 and the mode amplitudes are reduced by the application of I_{ded} up to ~500A. More importantly, the damping rate increases with I_{ded} . Formation of the magnetic islands induced by the magnetic perturbations potentially modifies the plasma equilibrium, density and temperature profiles due to the diffusion process in the ergodic region. In addition to those effects the experiments on TEXTOR with DED operation showed that the perturbation triggered the m/n=2/1 MHD mode and resultant modification of the plasma profile when I_{ded} exceeds the critical value of a few kA [8]. At the level of I_{ded} ~500A which is also much smaller than the critical I_{ded} for MHD mode onset, the width of the islands and the ergodic regions are much smaller than in the case shown Fig.5 (b). Significant changes of the plasma profiles are not observed for I_{ded}<500A in the experiments. The detailed mechanism for the suppression of AEs in the low I_{ded} region is not yet clear but violation of standing wave formation by phase mixing of the waves in the gap of Alfven resonances etc. is conjectured to play some role on this phenomena. This suppression of AEs by the magnetic field perturbation was also observed for the m/n=6/2 DED coil operation. If the weakly damped AEs excited at the plasma periphery can be suppressed by the small perturbation fields, even in a lager machine like ITER, without causing major deterioration of plasma transport, this method might be useful for the future fusion plasmas. However, more detailed estimations of the optimum perturbation field strengths modes to suppress AEs are needed.

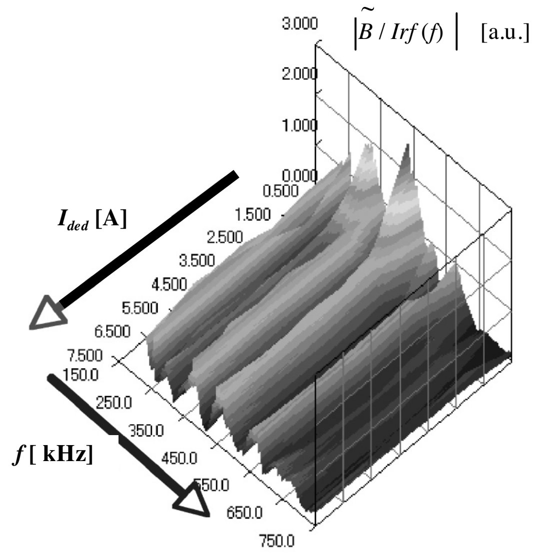

Fig. 7 Power spectrum of Mirnov coil signal normalized by Irf versus dc DED current. Bt=2.25T, $<n_e>$= 2x10^{19}m^{-3}, I_P=300kA

5. Summary

DED coils were used as an antenna to excite AEs, and coil impedance and Mirnov signal measurements indicated those excitations. When dc currents of only <500A were superimposed on the DED coils, the AEs were observed to be stabilized effectively.

Acknowledgments

The authors would like to thank Dr. N. Noda in NIFS for his valuable discussions. This work was supported by the NIFS Collaboration Research Program and also supported in part by the Grant-in-Aid for Scientific Research on Priority Areas from MEXT, Japan.

For Alfven eigenmode calculations by AE3D code, we express our gratitude to D. Spong (ORNL), M. Isobe (NIFS) and K. Ogawa (Nagoya Univ.).

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