Excitation of Alfven Eigenmodes using the DED Coil in the TEXTOR Tokamak

T. Shoji[1)], Y. Kikuchi[5)], A. Tsushima[2)], K. Toi[3)], N. Noda[3)], G. Matsunaga[4)]
K.H. Finken[5)], M. Jakubowski[5)], M. Lehnen[5)], O. Zimmermann[5)], R. Wolf [5)], A.G. Elfimov[6)]

1) Department of Energy Engineering and Science, Nagoya University 464-8603, Nagoya Japan

2) School of Engineering Division of Physics , Yokohama National University, Yokohama 240-8501, Japan

3) National Institute of Fusion Science, Toki-shi 509-5292, Japan

4) Japan Atomic Energy Research Institute, Ibaraki, Japan 311-0193

5)) Institute für Plasmaphysik, Forschungszentrum Jülich GmbH, EURATOM Association, Trilateral Euregio Cluster, Jülich D-52425, Germany

6) Institute of Physics, University of San Paulo, 05508-900, San Paulo, Brazil

Results from the first experiments to excite Alfven eigenmodes (AEs) in the TEXTOR tokamak plasma by using the dynamic ergodic diverter (DED) coils as an external antenna are presented. Notable features of AEs experiments using DED coils are exciting different modes around m/n=12/4, 6/2, 3/1 by changing the coil configuration, studying the effects of magnetic islands and edge magnetic fields ergodization on AEs when the rf current is applied for dc and AC DED operation, etc. The rf current of $\leq$ 4A with scanning the frequency 100kHz-1MHz is applied on the one of the DED coils. The coil impedance versus frequency is measured for the plasma (Ip = 350 kA, Bt = 2.25 T, n_e=2-3x10^{19} m^{-3}) with AC DED (1kHz, 1.5kA) and compared with the theoretical calculation. The excited waves are detected by the Mirnov coils installed around the torus.

1, Introduction

Weakly damped Alfven eigenmodes (AEs) excited by high energy ions such as alpha particles created by DT fusion reaction are recognized as one of important topics for confinement of alpha particles themselves in the International Thermonuclear Experimental Reactor (ITER). 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 eigenmodes activity driven by resonant energetic particles produced by ion cyclotron heating (ICH) and neutral beam injection (NBI) has been studied in different tokamak experiments [1, 2]. Energetic ion losses and resultant reduction of the neutron production accompanied with the appearance of toroidicity induced AEs (TAEs) have been observed [3]. Passively excited AEs in such experiments have difficulties in studying the characteristics of the damping and stabilities of the modes due to the driving terms of NBI and ICH. The active method combining excitation by externally introduced antenna with coherent detection of proving signals at the plasma edge and core has been performed in JET [4]. We use the DED coil 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

The DED consists of 16 perturbation coils wrapped around the high field side of the torus (poloidal extension: 70^0) as shown in Fig. 1 and generate a perturbation field which has Fourier components having resonance near the plasma edge. The perturbation field is not only static but also rotatable in the helical direction (predominantly in the poloidal direction). The AC frequency of the field goes up to 10 kHz, and the resulting poloidal rotation velocity can exceed the diamagnetic drift at the plasma edge. A four phase current up to 15 kA on the DED coils ergodise the surface magnetic field structure.

One or two pairs of the DED coils are used as the antennas for AEs excitation. The maximum rf frequency, current and voltage induced in the coils by using the rf amplifier are 1MHz, 5A and 75V (zero to peak values), respectively. The coil set can be chosen in several ways that excite the perturbation fields of the poloidal and toroidal modes m/n=12/4. 6/2 and 3/1 (the effective poloidal mode numbers are 20, 10 and 5, respectively) by using two rf amplifiers with phasing each other. The coil inductance is ~15 μH for m/n=3/1 mode at 100kHz. The magnetic perturbation field against the total field $\delta B/B$ is estimated as ~$5x10^{-6}$ (rf current ~5A) at r/a=0.9 (q=3) for m/n=3/1. In order to estimate the antenna loading for AEs excitation, the coil current and the voltage are measured by the Rogowski coil and the capacitive pick-up (Fig. 2). The capacitive pick-up uses a thin dielectric ceramic plate for the isolation from the high voltage in the DED operation. The small rf signal can be superimposed on the large 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 positions in toroidal and poloidal directions.

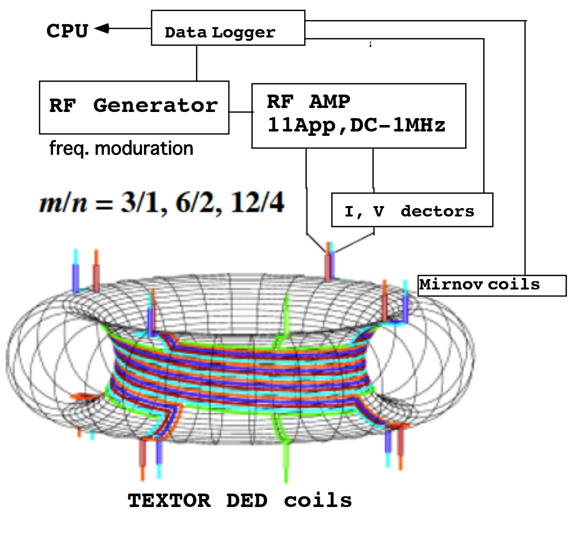

Fig. 1 DED coils and AEs antenna system

2, Coil impedance measurements

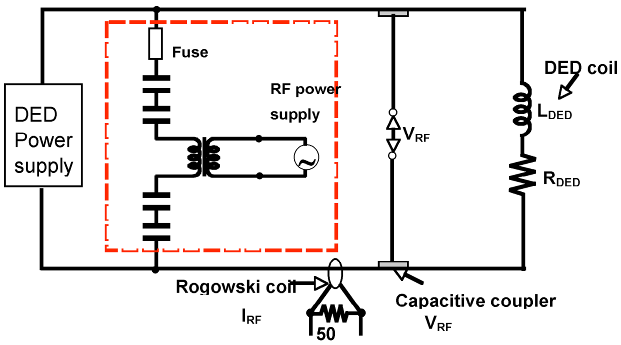

Fig. 2 Rf antenna circuit and impedance diagnostics

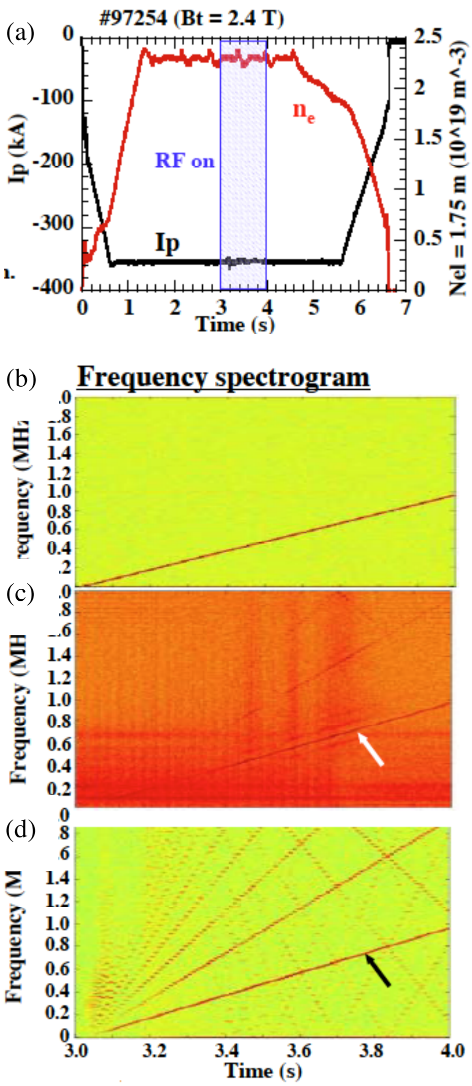

Fig. 3 (a) Ip and ne of TEXTOR shot. Frequency spectrum of rf generator (b), coil voltage (c) and current (d), respectively.

In Fig. 3, an example of the coil voltage and the current are shown for typical TEXTOR plasma discharge where toroidal field Bt, line averaged electron density ne and plasma current

Ip are 2.4 T, 2.3×10^{19} m^{-3} and 350 kA, respectively. The preliminary results shown here are obtained by using the DED coil configuration of 3/1 mode. The rf current with the frequency sweeping from 100 to 300kHz in 1 sec is applied during the flat top period of the discharge (Fig. 3(b)). The frequency spectrum of voltage pick-up and current signals show the driving frequency peaks and also its higher harmonics. The voltage pick-up is more affected by the plasma noise than current one due to the high impedance detection system. We observed some high impedance peaks in the frequency spectrum which is attributed to the parallel resonance with the stray capacitance of the DED cables. When the plasma exists the real part of the coil impedance (same phase with the coil current) increases and the circuit resonance peaks become small and broader. The Mirnov coil placed almost 90 degrees away from the rf coil in poloidal direction detects the rf magnetic field perturbation during the plasma shot. The analysis on the AEs evidences in Mirnov signal is now underway.

3, Impedance measurement with DED operation

The unique feature of DED is the rotation of the magnetic perturbation. It is observed that the induction of the plasma toroidal rotation comparable to the one achieved by ~1MW of unidirectional NBI [6]. These features are expected to influence on the damping and the stability of AEs. The AC DED current is ramped up to 1.5kA (1kHz) during the plasma shot and the rf current of ~4A (the frequency is swept in 1 second) is superimposed on the DED current at almost the end of the rump as shown in Fig. 4(a). The rf signals of coil current and voltage can be still obtained under this condition with a little DED AC frequency (1kHz) modulation (Fig. 4(b)). An example of the power spectrum of the change in the coil loading resistance from the vacuum shot $\Delta r_p(\omega)$ is shown in Fig. 5. There are some peaks around 370kHz in this case. The TAE modes and the coil impedance for m/n=3/1 are calculated to compare with the experiments. The cylindrical plasma density and current profiles are assumed as $n_e=n_0(1-0.95\cdot r^2)^{1.1}$, $j_p=j_0(1-0.95\cdot r^2)^{2.5}$ which are determined from the experimental data. The profile of Alfven continuum frequency is shown

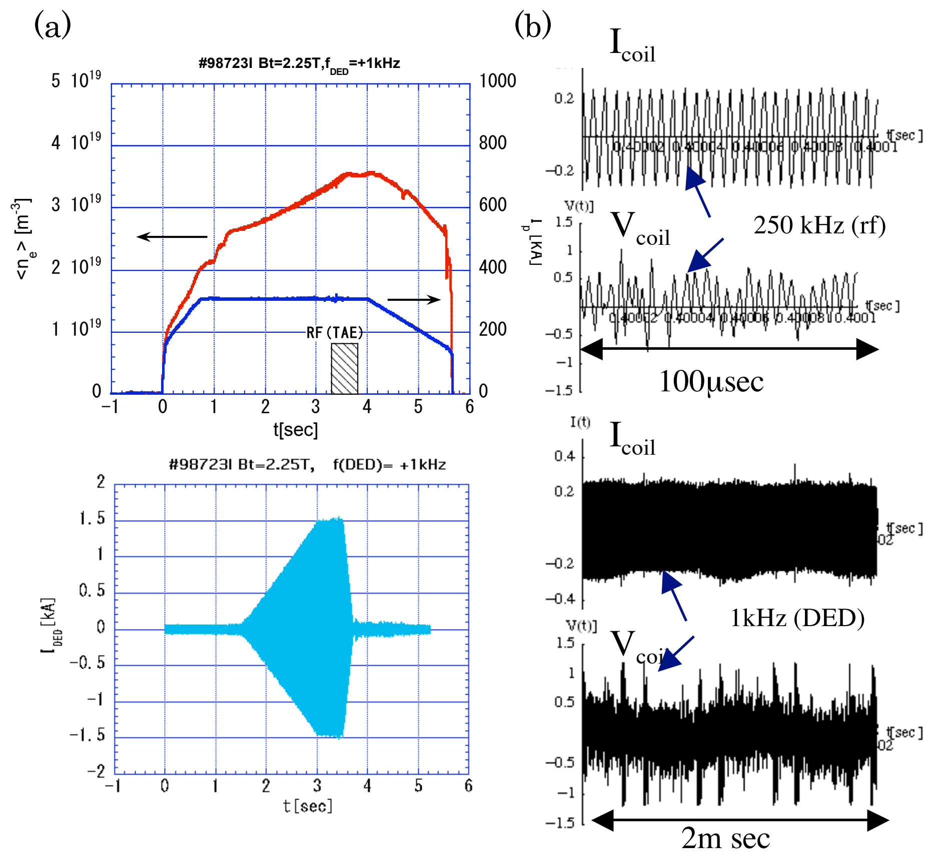

Fig. 4 (a) Ip and ne and DED current in AC(1KHz, 1.5kA max) mode, and (b) the coil rf current and Voltage signals in different time scales.

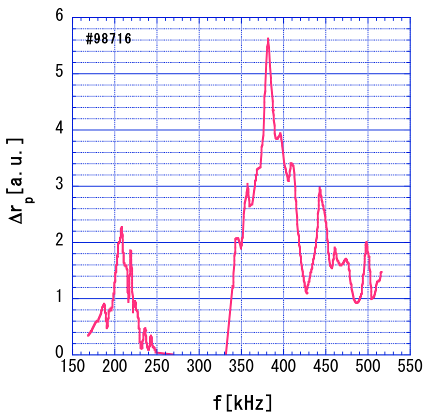

Fig. 5 Power spectrum of the change in the coil loadoing resistance from the vacuum. Bt=2.25T, <ne>= $3.2\times10^{19}m^{-3}$,I_{DED}=1.5kA, +1kHz.

for n=-1, m=1, 2, 3, 4 which are dominantly excited by the m/n=3/1 coils (Fig. 6(a)). The coil impedance has peaks around 209 kHz and 373 kHz (Fig.6 (b)). The lager is similar to the one observed in the experiment. The radial absorption profiles of the wave in these frequencies indicate that the absorption occurs at the plasma periphery region (Fig. 6(c)).

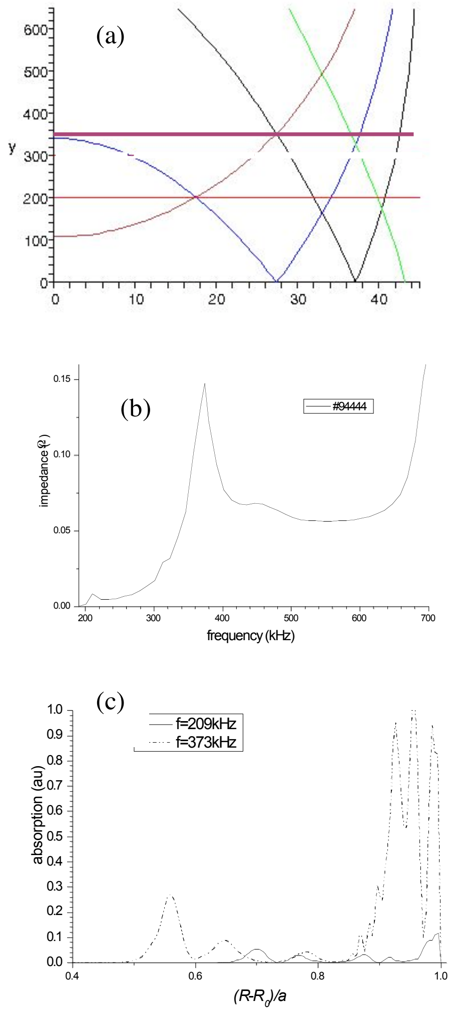

Fig.6 (a) Alfven wave continuum frequency for n= -1, m=1,2,3,4, (b) coil impedance spectrum and (c) power absorption profile. n_{e0}=3.2x $10^{19}m^{-3}$, Bt=2.25T, D_2 q_0=1.25, Ip=300kA

4, Summary

The DED coils are used as an antenna to excite AEs (TAE) and the preliminary experiment for impedance measurement has been performed with AC DED operation. The further detailed measurements are needed to investigate the effects of the active modification of the plasma periphery by DED on AEs (TAE).

5, Acknowledgement

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