§40. Frequency Sweeping of Reversed Shear Alfven Eigenmodes during Counter Neutral Beam Current Drive

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In high beta regime, magnetic configuration in LHD evolves intrinsically to a reversed magnetic shear (RS-) configuration because of large Shafranov shift. The RS configuration can also be generated by intense counter neutral beam current drive (NBCD) even in low beta plasmas. In such low beta plasmas, Alfven eigenmodes, called reversed shear Alfven eigenmodes (RSAEs) of n=1 were observed together with geodesic acoustic mode (GAM) driven by energetic ions in the cases of Rax=3.7m to 3.8m. This RSAE has a symmetric frequency sweeping, that is, downward to upward, when the minimum of the rotational transform ($\iota/2\pi$) evolves in time from more than 0.5 down to less than 1/3, as shown in Fig.1 [1,2]. The eigenfunctions of the RSAE were calculated by a numerical code for the Alfven eigenmode analysis of three dimensional plasmas, AE3D [3]. It was confirmed that the eigenfunction of the RSAE has a localized nature around the $(\iota/2\pi)_{min}$ layer. Accordingly, we assume that the observed RSAE is a localized mode. In RS-tokamak plasmas, the frequency is swept to one direction, that is upward sweeping, when the minimum of the q-value, q_{min} is decreased in time[4]. On the other hand, downward sweeping is rarely observed. Accordingly, the frequency sweeping of RSAE in LHD has a marked difference with the RSAE in a tokamak. The magnetic configuration of LHD is three dimensional, but has large toroidal period number N=10. The toroidal mode coupling is very weak for TAE and RSAE in LHD, because of large N. This means that TAE and RSAE in LHD have very similar to those in tokamaks. Accordingly, RSAE theory developed for a tokamak plasma will be applicable to RSAEs in LHD. The existence criterion is given by Q>1/4, where Q is the potential function in the RSAE wave equation [4]. Q consists of four terms as $Q=Q_{hot}+Q_{tor}+Q_{pressure}+Q_{den}$, where

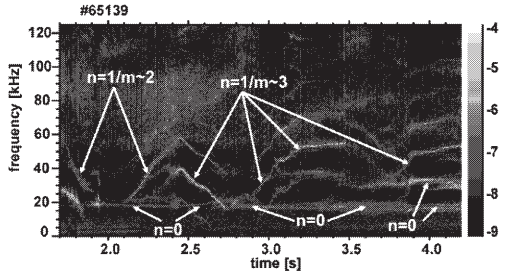

Fig.1 Spectrogram of magnetic probe signal in an RS plasma. Coherent mode with n=1 is RSAE and that with n=0 is GAM driven by energetic ions. Other coherent modes are generated by nonlinear coupling between RSAE and GAM.

Q_{hot}, Q_{tor}, $Q_{pressure}$ and Q_{den} express respectively contributions from energetic ions, plasma toroidicity, pressure gradient and density profile effect [5]. RSAE in LHD has also a peculiar character: this mode propagates in the electron diamagnetic drift direction, that is, negative frequency mode. This suggests the hollow profile in energetic ion pressure. Moreover, the curvature of the q-profile in the RS configuration is negative, that is, $q''(r_o)<0$(r_o: radius of the zero magnetic shear layer), while that in the tokamak RS configuration is positive $q''(r_o)>0$. Shape of energetic ion pressure and $q''(r_o)$ strongly affect the direction of the frequency sweeping.

In the downward sweeping phase, Q_{hot} contributes to the existence of RSAE dominantly, but other three contributions impede the existence. In the upward sweeping phase, Q_{tor}, $Q_{pressure}$ and Q_{den} contribute to the existence because shallow magnetic well at the zero shear layer is expected and density profile is hollow. The central electron temperature is slowly decreasing with the increase in counter plasma current by NBCD, which means Q_{hot} slowly decreases in time. Accordingly, $Q_{hot}>Q_{tor}+Q_{pressure}+Q_{den}$ in the downward sweeping phase and $Q_{tor}+Q_{pressure}+Q_{den}>Q_{hot}$ in the upward sweeping phase are expected. If an energetic ion effect prevails over the other effects by electron heating using ECH, RSAE may be suppressed in the upward sweeping phase. This was tested in an RS-plasma, where ECH was applied in the upward sweeping phase. Figure 2 shows the spectrogram of magnetic probe signal. Applied ECH clearly suppresses RSAE in the upward sweeping phase, although RSAE reappears in the latter half of an ECH pulse. This result seems to support the above discussion on the existence of RSAE. Quantitative analysis is left for a future study.

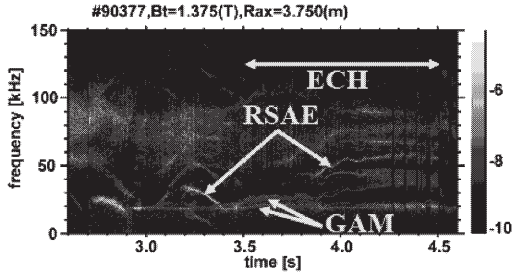

Fig.2 Spectrogram of magnetic probe signal in an RS-plasma, where ECH is applied in the upward sweeping phase of the RSAE frequency. Just after the switch on of ECH, the GAM frequency rises noticeably due to temperature rise. RSAE is suppressed for ~0.4s in the ECH pulse.

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