§8. Two Frequency Wave Excitation Experiments

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In order to perform controlled nonlinear wave physics experiments, we have proposed two frequency wave injection. In fiscal year 2012, we installed a new waveguide array antenna for direct excitation of lower hybrid wave (200 MHz) in the TST-2 spherical tokamak device. Using the new antenna, plasma current of up to 8 kA was obtained non-inductively. We measured the wavenumber and polarization of the excited waves in such RF start-up plasmas. In addition, two frequency RF power was injected and nonlinear plasma responses were investigated.

An array of magnetic pickup coil was installed at the weak field side of the plasma. The array can be rotatable and movable, and toroidal-, poloidal- radial-wavenumbers and polarization can be measured using several reproducible discharges. The measured wavenumbers satisfy the dispersion relation of lower hybrid wave, and the polarization agrees qualitatively with the expectation. According to the calculated dispersion relation, the wave can propagate through the edge region, but cannot penetrate deep into the core region. The measured parallel wavenumber is about one sixth of the dominant wavenumber of the new waveguide array antenna, which is expected to penetrate deep into the core. Thus, the measurements suggest that the observed wave is not the dominant part of excited wave, which might be absorbed at the core region before reaching the magnetic pickup coils.

Figure 1 shows the discharge waveform of a two frequency RF power injection discharge. The plasma current was ramped up without using the center solenoid, and the current is sustained by the RF power. In this case, the signal generators with frequencies 200 MHz and 200.25 ± 0.2 MHz were used and they were combined and fed to the RF power amplifier system. The frequency of the second signal generator was swept sinusoidally. Thus, the injected power has a beating feature as shown in the black curve in Fig. 1 (b). Figure 1 (c) shows the power spectrum of the line integrated electron density $n_e l$ around the outboard boundary. A clear sinusoidal spectral behavior in the frequency range of 0.25 ± 0.2 MHz can be seen, which represents a nonlinear coupling of the injected two frequencies because the frequency corresponds to the frequency difference of the injected RF waves.

In order to reveal the feature of the nonlinear coupling, the relationship between the injected beating power P_{beat} and the response in $n_e l$ was investigated. Figure 2 shows the response of $n_e l$ and P_{beat} as a function of frequency difference. The difference between them indicates the nonlinear response (i.e., gain) of the plasma. Figure 3 shows the dependence on P_{beat} for four representative frequency differences (104, 200, 236, 332, 400 kHz). Two dotted lines (P_{beat}^2 and P_{beat}^4) are plotted for a guide. The dependence P_{beat}^2 can be interpreted by a linearized ponderomotive force, which is appropriate when the beating power is much smaller than the average power. The dependence P_{beat}^4 may appear when the beating power is comparable to the average power. In addition to the poderomotive force, we should take into account the excitation of Alfven eigen modes, which can be excited for the low aspect ratio plasma in those frequency ranges. So far we have not yet obtained conclusive results, and further experiments are required.

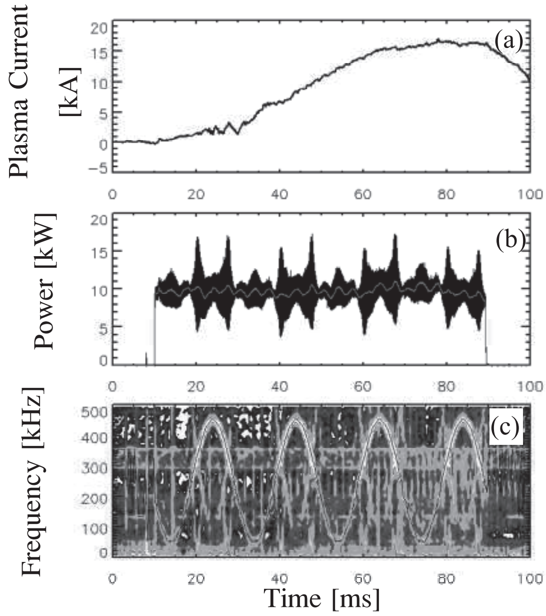

Fig. 1 Time evolution of the plasma current (a), RF injection power (b) and the spectrogram of microwave interferometer signal.

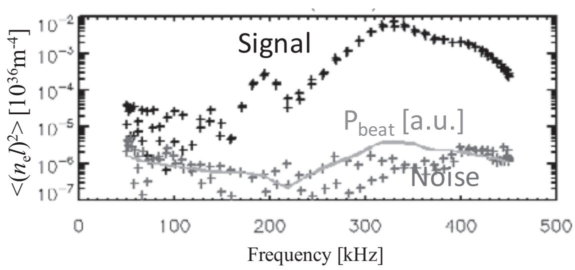

Fig. 2 Response of the line integrated electron density and the beating power as a function of frequency difference.

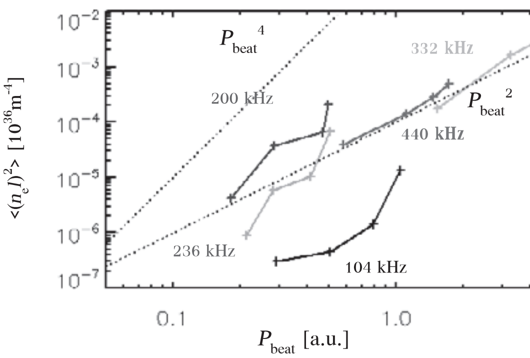

Fig. 3 Beating power P_{beat} versus nonlinear components of the line integrated electron density.