Measurement and analysis of helicon wave couplings for current drive in KSTAR

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Helicon wave coupling to KSTAR plasma for current drive [1] was analyzed through surface impedance [2] analysis and low power experiments. The surface impedance analysis showed that slow wave, which may be an unfavorable mode for the helicon wave current drive, can be coupled to the plasma when parallel electric field components exist at the antenna surface, as Fig. 2 shows. The slow wave coupling increases when mode coupling is engaged. The term of mode coupling expressed in this article is a phenomenon in which a parallel electric field is generated or enhanced owing to the off-diagonal elements in the plasma impedance matrix even if small or no relevant antenna current components are existing.

However, the slow wave contribution to the loading resistance is lower than the fast wave one by more than an order of magnitude when the electron density was moderate at the plasma boundary, $n_e > 1\text{x}10^{18}/\text{m}^3$ and the pitch angle mis-alignment was less than 10 degrees. If $n_e > 3\text{x}10^{18}/\text{m}^3$, the slow wave portion of loading resistance is still below 10% if the mis-alignment was lower than 45 degrees. Additionally, the measurement also did not show any evidence of significant slow wave coupling when the pitch angle was scanned, as Fig. 3 shows for H-mode discharge.

The low level RF characteristics of the fabricated low power TWA [3] showed good agreement with the designed ones in terms of a two-port scattering matrix with the center frequency and bandwidth. The TWA, installed at an off-mid-plane, also showed good coupling capability in L- and H-mode plasmas. The traditional means to control RF coupling were effective. The control of the radial outer-gap by moving the plasma outer boundary from 8 to 4 cm at the mid-plane in the L- and H-mode discharges doubled the coupling defined by the absorption coefficient *A* almost linearly as

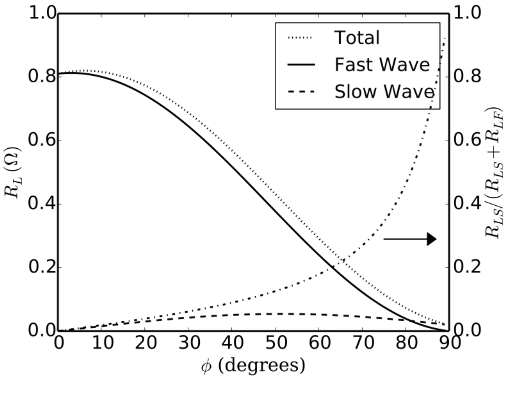
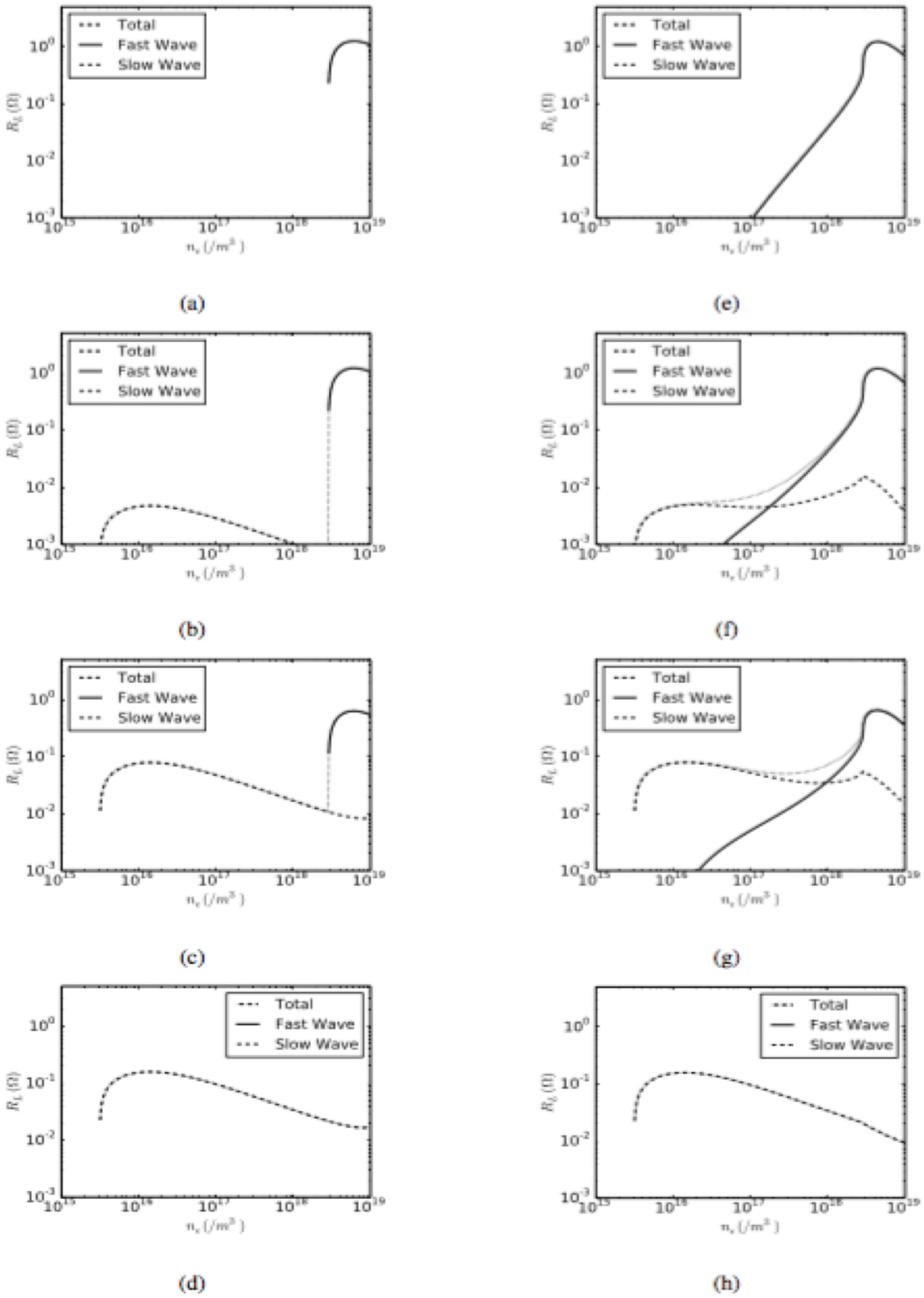


Figure. 1 Loading resistance R_L versus alignment angle for coupled fast and slow waves. The right axis shows the slow wave portion.

in Fig. 4. Hardly any plasma confinement degradation was observed during plasma movement.



(a) (e)

(b) (f)

(c) (g)

(d) (h)

Figure. 2 R_L of fast and slow decoupled waves for pitch angle mis-alignments of (a) 0, (b) 10, (c) 45, and (d) 90 degrees and the corresponding coupled cases for mis-alignments of (e) 0, (f) 10, (g) 45, and (h) 90 degrees. The parallel refractive index is 3.

Local gas puffing was also quite effective in enhancing the coupling, although the gas nozzle was not magnetically connected to the antenna surface. A small degradation of the confinement, 13% decrease of H_{89}, was observed during gas puffing.

In principle, the TWA is load resilient to some extent. A coupling measurement in an ELMy H-mode discharge showed that the TWA is resilient to L-/H-mode transition and ELMs. Small reflection appearing during short periods of large ELM bursts shown in Fig. 4 can be circulated by a circulator or hybrid decoupler.

It was determined that too much coupling is a possible problem for accurately maintaining the parallel refractive index $n_{\parallel}$. Large loading distorts the assumed relationship between a small loading resistance and the mutual reactance resulting in distortion of the phase relationship between radiating straps. A much larger number of straps with small loading can solve this issue.

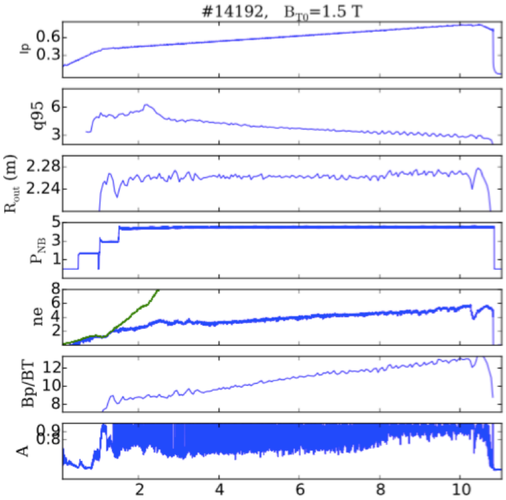


Figure. 4 Magnetic pitch scan performed by increasing the plasma current I_p in the NBI heated H-mode discharge #14192 at B_0=1.5 T.

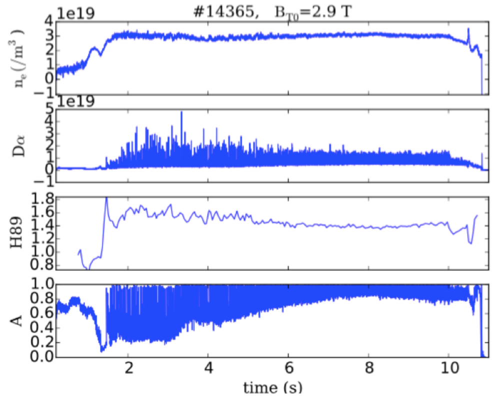


Figure. 3 Evolution of the H-mode discharge #14365 at B_{T0}=2.9 T. Local gas puffing is applied from 4 to 8 s.

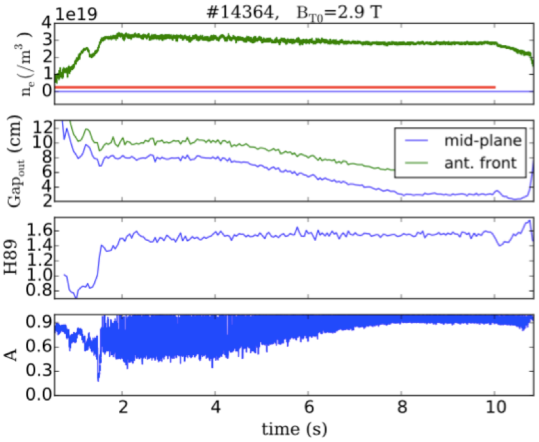


Figure. 6 Evolution of H-mode discharge #14364. The outer-gap Gap_{out} on the mid-plane is controlled from 8 to 3 cm during the time period from 4 to 8 s.

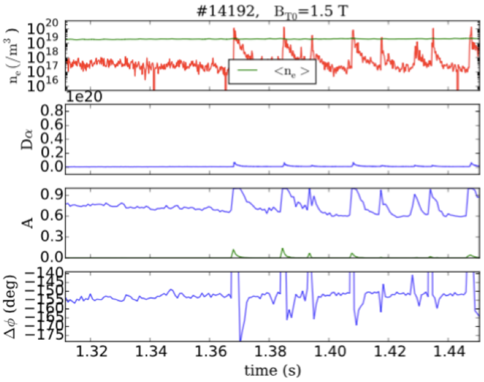


Figure. 5 Detailed evolution of ELMy H-mode discharge.

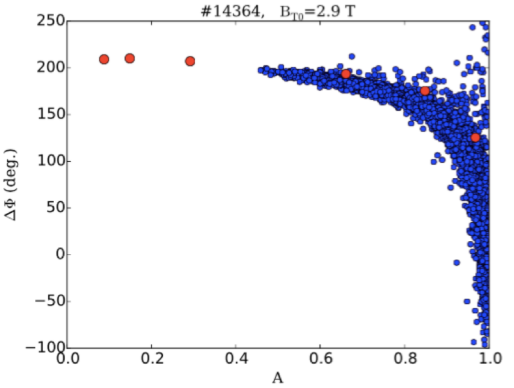


Figure. 9 Antenna phase difference versus absorption coefficient for H-mode discharge #14364 (blue dots) and antenna simulation with absorber in front of antenna (red dots).

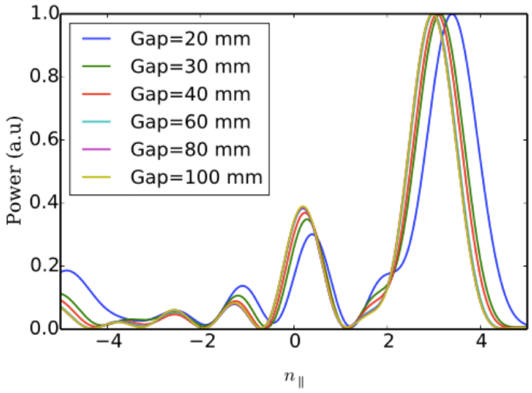


Figure. 7 Calculated power spectrum of the TWA for various gaps between the front surface of the Faraday shield and the absorber. Three lines for Gap=60-100 mm are overlaped.

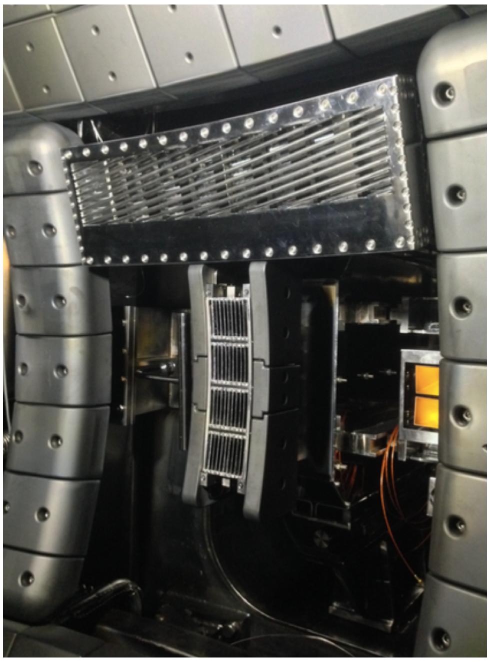


Figure. 8 Installed mock-up TWA made. The LHCD grill launcher at the mid-plane can be seen at the center of the photograph. Both sides of the TWA are protected by graphite poloidal limiters. The horn antennas used for millimeter-wave reflectometry are also shown.

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References

[1] V. L. Vdovin, Plasma Phys. Reports, 39, 115(2013)

[2] M. Brambilla, Nucl. Fusion, 35, 1265(1995)

[3] C.P. Moeller, R.W. Gould, D.A. Phelps, and R.I. Pinsker, In 10th Topical Conference on RF power in Plasmas, AIP Conf. Proc. 289, 323(1994)